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DISTRIBUTED INTERACTIVE SIMULATION
VIRTUAL CASSETTE RECORDER
(DIS VCR)
A DATALOGGER
WITH VARIABLE-SPEED REPLAY

THESIS

Jonathan L. Fortner, Captain, USAF

AFIT/GE/ENG/94D-10

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

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Jonathan L. Fortner, B.S.E.E.

Captain, USAF

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Approved for public release; distribution unlimited

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Abstract

The overall objective of the Distributed Interactive Simulation Virtual Cassette Recorder (DIS VCR) is to add a flexible replay capability to any DIS environment and specifically to the Remote Debriefing Tool (RDT). The DIS VCR's abilities include selective filtering of incoming DIS Protocol Data Units (PDUs), variable-speed replays, ability to pause, fast-forward, rewind, efficient data storage and retrieval, and an interface that simplifies the execution of those functions. The thesis includes a DIS VCR-compatible design for concurrent replay of audio extracted from signal PDUs and an extension to the replay design that supports unmodifiable rendering or receiving applications. For variable-speed replays, we created a scalable simulation clock and a new PDU (the Replay PDU). Applications modified for replays use the simulation clock to govern their dead reckoning algorithms while the DIS VCR uses it to control the timed release of stored PDUs. The Replay PDU communicates mode and speed changes between the DIS VCR and replay-modified applications. The DIS VCR's full functionality was successfully demonstrated at the 1994 AFA convention.

DISTRIBUTED INTERACTIVE SIMULATION VIRTUAL CASSETTE RECORDER

(DIS VCR)

A DATALOGGER WITH VARIABLE-SPEED REPLAY

I. Introduction

1.1. Overview

The past few years have seen remarkable advances in the area of Distributed Interactive Simulation (DIS). The DIS environment allows military units from around the country to participate in mock training exercises without a large commitment of resources (4:1).

Recent developments have demonstrated the capability to "integrate live aircraft into a Distributed Interactive Simulation" (1:5). Gardner (1) developed a Remote Debriefing Tool (RDT) that emulates, and for some functions improves on, the Red Flag Measurement and Debriefing System (RFMDS). The proof-of-concept for RDT demonstrated for the first time that we can capture live range data from a military exercise, transmit it across a wide-area network, and view the mission in real-time using the RDT software. Since the RDT software suite can replay the scenarios from stored RFMDS data, pilots no longer have to land at Nellis AFB to get the benefit of RFMDS in "reconstructing the missions (1:3)," a critical part of the training that helps pilots and crews learn. However, RDT's replay capability lacks the flexibility of RFMDS, and requires too much disk storage. For remote debriefings there is a long arduous process to get the data and set it up at a remote location.

The Advanced Research Projects Agency (ARPA) has continued funding RDT to improve its mirroring of RFMDS capabilities. They envision replay functionality that is very similar to what

every home Video Cassette Recorder (VCR) has. Even Gardner recommends a VCR type application for DIS Protocol Data Units (PDUs) as an "area where additional research is warranted" (1:146).

Another important part of mission reconstruction is the replay of UHF communications. The RFMDS system receives eight UHF channels of Red Flag participant chatter during the exercises and stores it on magnetic tape to replay during mass debriefings. For future research in this area, Gardner says,

The DIS standard can be employed to transmit and receive digitized voice data. Hardware and software packages exist on the market today which might be adapted for use with RDT. The ability to monitor radio communications would be a significant step forward for the remote debriefing concept. (1:146)

Audio significantly contributes to the realism of RFMDS mission replays, where realism is a key factor in the effectiveness of the debriefing.

In time, simulations will provide a relatively inexpensive, completely realistic virtual environment that can measurably enhance our war-fighting capability. As an example, imagine a purely synthetic battlefield environment that looks and feels like southern Iraq, including representative interactive enemy forces. Now immerse pilots in this artificial battle zone by putting them in virtual cockpits (3) and giving them realistic targets or defensive objectives. After completing their mission, we could replay the scenario and debrief the pilots on their effectiveness. After such training, the actual combat area is more likely to be familiar. This familiarization training could potentially save lives and aircraft that were previously lost because of pilot disorientation.

1.2. Thesis Statement

Develop a flexible replay capability for the RDT. This tool must be designed and implemented independent from RDT, so that any DIS application can benefit from it. Since the DIS standard (2) provides a way to send audio across the network, the software's design can

encompass the capturing and timely replay of that audio. This must be accomplished using the same off-the-shelf hardware and software available to the RDT project.

The DIS Virtual Cassette Recorder (from here on known as the DIS VCR) concept is shown in Figure 1.1.

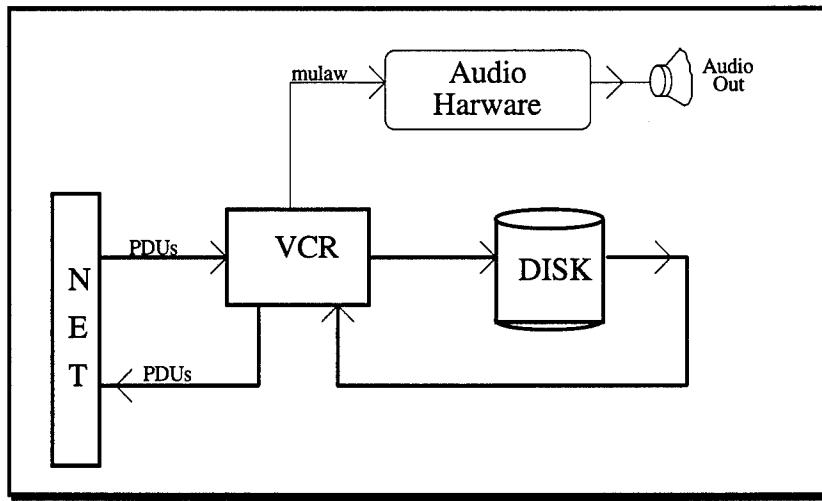


Figure 1.1. DIS VCR Basic Concept

A successful DIS VCR design and implementation will have capabilities as follows:

1. Capture DIS PDUs from the network and store them on disk.
2. Filter incoming PDUs to isolate a specific entity or range of entities, particular exercise, host, or site IDs, and specified PDU types.
3. Replay recorded PDUs at variable speeds, with the ability to pause during the replay.
4. Fast-forward and rewind through a DIS recording.
5. Provide an interface that reduces a user's learning curve and provides for easy identification and loading of DIS recordings.

1.3. Scope

The scope of this thesis effort will include the research, design, and implementation necessary to deliver a system that selectively records and flexibly replays a limited number of DIS PDU types. The design will be extended to cover the modifications needed to include audio derived from DIS signal PDUs (2:74) .

1.4. Assumptions

This section lists assumptions that were made in determining the full scope of this thesis project.

1. The DIS VCR user could be anyone in the DIS community.
2. The hardware and software development tools needed for the DIS VCR will not exceed that available to RDT (1:8).
3. Existing network daemons will be used.
4. The DIS VCR will be independent of any rendering scheme.
5. PDUs will be replayed in the same order in which they arrived.

1.5. Basic Approach

The DIS VCR can be divided on the top level into two parts; record and play. Record is subdivided into getting filtered PDUs from the network and storing them to disk. Play is more complex in that it must be able to get PDUs from the disk, send them across the network, control the speed at which they are sent, pause and resume during replays, and allow the user to move quickly to some specified time in the data.

1.5.1. Recording. This component of the DIS VCR takes PDUs supplied by the network daemons, checks the PDUs to see if they fit the user specified parameters, then stores all matching PDUs to disk. As identified later, PDU storage to disk is the only real difficulty for recording.

1.5.2. Play. The network interface for play is nearly the same as record. When a replayed PDU is ready to send, it is handed off to the network daemon. Timing this hand-off is critical and is the main driver of the design for play. The next few sections break up play's functions and describe the basic approach to each.

1.5.2.1. Speed. Since DIS is a "real-time" environment, it is not equipped to deal with an other-than-real-time replay of a simulation. Therefore, it is necessary to create a clock that moves at the desired speeds making it easy to time-release PDUs. This design decision carries over to the receiving application since dead-reckoning is normally performed using real-time clocks.

1.5.2.2. Fast-Forward and Rewind. Unlike your typical home VCR, the DIS VCR only allows fast-forwarding or rewinding from the stop mode. To add fast-forward or rewind, there must be a way to determine where in the file a specific time falls. The difficulty is that PDUs are stamped with a time offset since the beginning of the hour (2:102); therefore, we need a way of marking time blocks.

1.5.2.3. Pause. To pause, the DIS VCR stops sending PDUs at the current point in the data stream. It resumes from there when pause is released. However, the application must not drop active entities due to a lack of PDUs (2:25). This requires modifications to the receiving application or a method for ensuring PDU updates are sent by the VCR at five second intervals (see section 3.7).

1.5.2.4. File Selection. For the DIS VCR, we need a convenient way to select a data file and some visual data that identifies which recording is selected and what it contains. In reality, record will need to store the file data that is used to identify it.

1.6. Design Philosophy

Re-inventing the wheel takes considerable time and effort. It is better to make full use of existing code and high-level tools that will significantly increase productivity and allow time to concentrate on ease-of-use and functionality. The design and implementation of the DIS VCR will follow this philosophy.

1.7. Thesis Organization

The remainder of this thesis is divided into five chapters and an appendix. Chapter II covers all relevant background material concerning DIS, simulations, and dataloggers. Chapter III discusses the system design and breaks it down into the components that make up the DIS VCR. The implementation of the design is found in Chapter IV which contains the details on how the solutions to replay were coded. In Chapter V, performance data and its relevance is discussed. Finally, Chapter VI summarizes this document, identifies the contributions of this work, and recommends future enhancements and research. To complete the thesis, a DIS VCR user's manual is included in Appendix A.

II. Background

2.1. Introduction

"Distributed Interactive Simulation (DIS) is a time and space coherent synthetic representation of world environments designed for linking the interactive, free play activities of people in operational exercises" (2:1). This chapter covers DIS concepts that directly apply to this thesis, applicable elements of the Remote Debriefing Tool (RDT), and current work on dataloggers.

2.2. Distributed Interactive Simulation

The DIS standard (2) provides a way for geographically separated simulators to interact with each other via network communications. Distributed means that no single computer controls the simulation. Each locality is responsible for the rendering of entities based on incoming Protocol Data Units (PDUs) and local copies of common terrain and models (e.g. tanks, fighters and naval vessels). Local applications must send entity update PDUs when dead-reckoning thresholds are exceeded or five seconds have elapsed (1:14-15; 6:13-15).

The DIS standard defines 26 PDU types, but most applications only use a few. The initial design and implementation of the DIS VCR will support the entity state, fire, detonation, remove entity, and emissions PDUs. The following sections describe the PDU structures including the signal PDU that will be used for the audio design.

2.2.1. A Common PDU Header. The fields that are common to all PDUs are depicted in Figure 2.1. The first field identifies the DIS version the application is using. The DIS VCR uses version 2.0.3 and only captures PDUs with a three in this field. The exercise ID is used to identify the PDUs of participants from the same simulation. The participants agree in advance on the value

PROTOCOL VERSION	8-bit enumeration
EXERCISE ID	8-bit unsigned integer
PDU TYPE	8-bit enumeration
PROTOCOL FAMILY	8-bit enumeration
TIME STAMP	32-bit unsigned integer
LENGTH	16-bit unsigned integer
PADDING	16 bits unused

Figure 2.1. Common PDU Header Fields

for this number. DIS applications must be able to filter out PDUs which do not have the proper exercise ID. The next two fields, PDU type and protocol family, identify the portion of the PDU following the header. They can be used to select only certain PDU types for a particular recording or replay. The time stamp holds the time past the hour when the data in the PDU is valid (2:102). It is represented as the number of DIS time units, roughly equal to 1.676 microseconds each, since the beginning of the hour. This value is shifted into the upper 31 bits, and must be shifted back before using it. The length field is the total number of bytes for the PDU, including the header. This key field is used in applications to copy the right amount of data to and from the network daemons. The length field is central to the PDU storage and retrieval scheme for the DIS VCR. The last field is padding that allows for future growth.

2.2.2. Entity State, Fire, and Detonation PDUs. The entity state, fire, and detonation PDUs are the three most important PDU types for most DIS applications. However, the DIS VCR does not perform any rendering, making the full details of these PDUs unimportant. Nevertheless, the VCR must account for the differences in the PDU lengths shown in Figure 2.2. Although the

PDU TYPE	PDU LENGTH
Entity State	144 bytes + articulation parameters
Fire	96 bytes
Detonation	108 bytes

Figure 2.2. PDU Lengths by Type

layout for each of these PDU types differs significantly, they have identical entity ID fields immediately following the header, as shown in Figure 2.3. For fire and detonation PDUs, these fields identify the firing entity, not the weapon (2:112-114).

PDU Header	See Fig 2.1
Entity ID	
- Site	16-bit unsigned integer
- Application number	16-bit unsigned integer
- Entity	16-bit unsigned integer

Figure 2.3. PDU Entity Identification Fields

2.2.3. The Signal PDU. This PDU has the same header and entity ID fields as the others. However, the entity ID "may represent just the radio or an entity containing the radio" (2:167). The field mapping for the signal PDU is shown in Figure 2.4.

FIELD SIZE (bits)	FIELD NAME	DATA TYPE
96	PDU HEADER	See Figure 2.1
48	ENTITY ID	See Figure 2.3
16	Radio ID	16-bit unsigned integer
16	Encoding Scheme	16-bit enumeration
16	TDL Type	16-bit enumeration
32	Sample Rate	32-bit integer
16	Data Length	16-bit integer
16	Samples	16-bit integer
8	Data #0	8-bit unsigned integer
	:	
8	Data #n	8-bit unsigned integer

Figure 2.4. Signal PDU Fields

The DIS standard specifies that "8-bit mulaw encoding, sampled at 8Khz, shall be supported by all DIS radio simulators" (2:74). To simplify the audio design, mulaw encoding is assumed. Therefore, the encoding scheme field is set to the mulaw enumeration.

2.3. RDT Versus RFMDS

In the last chapter, it was pointed out that RDT's replay ability lacked flexibility and was a long, arduous, space hungry process. In this section, that replay process is examined and compared to the RFMDS capability.

2.3.1. Data Conversion for Remote Sites. The process of archiving, transferring, and converting an RFMDS recording is illustrated in Figure 2.5. Since live mission data, including audio, is stored to hard disk (4:Sec 3, 8), the first step is to archive it to a 9-track tape for shipment to the debriefing site. At the remote site, the raw data must be transferred to a hard disk using

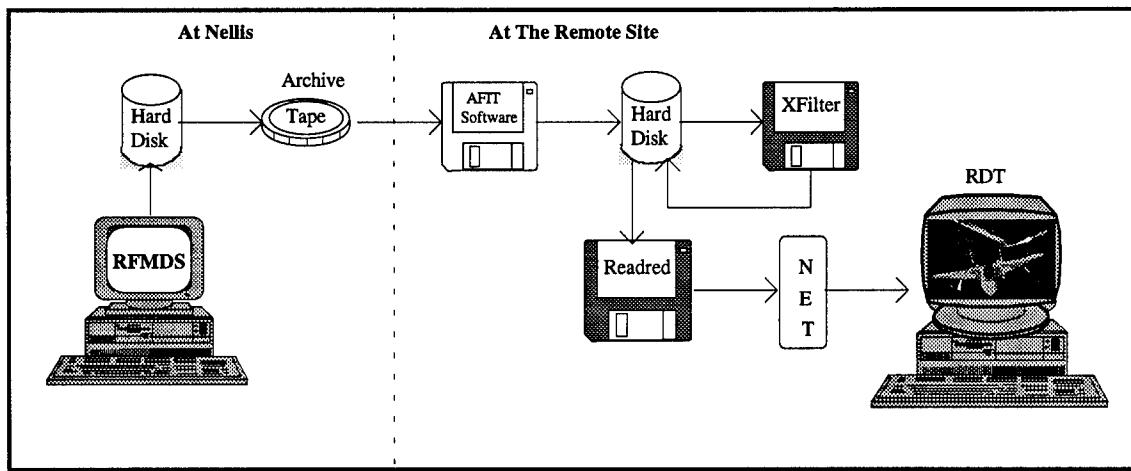


Figure 2.5. Getting RFMDS Data to a Remote Site

special AFIT software. The next step uses the RDT *Xfilter* program to trim off unused RFMDS messages (1:133). The new file can now be used as input for the RDT *readred* software which puts PDUs onto the network.

Table 2.1 shows the disk space requirements for raw and filtered data and lists each form's PDU count. Gardner discovered that he could use DIS dead reckoning (position predicting) algorithms to reduce the *readred* PDU count to 184,078 using a high-fidelity movement threshold of one meter and to 46,596 using a 10 meter threshold (1:18,133). He also noted that 38% of

Table 2.1. RFMDS Converted Data Sizes and PDU Counts

LENGTH	RAW	XFILTERED	RAW PDU COUNT	1 METER DEAD-RECK PDU COUNT	10 METER DEAD-RECK PDU COUNT
44.65 mins	184MB	123MB	797,182	184,078	46,596

the CPU time was spent converting RFMDS floating point to the IEEE format used in DIS (1:94). The overhead severely limited *readred*'s maximum speed and caused it to lag behind range time on occasion. Our design for the DIS VCR reduces the disk space requirements for remote debriefing sites and significantly increases the speed and functionality for replays.

2.3.2. *Readred's Replay*. RDT tests with an RFMDS user revealed that the two most significant capabilities missing from RDT were UHF communications and flexible replay. Even Gardner states that "a variable-speed replay and pause capability are the backbone of the debriefings that follow the Red Flag missions" (1:141-143).

Readred replay was designed to run at one speed from start to finish. If stopped, it has to be restarted from the beginning. Mission analysts need the ability to slow the action down and pause at critical moments to provide an effective analysis. Fully functional replay software, combined with RDT's capabilities, will provide the necessary tools for a thorough mission evaluation.

2.4. Datalogger Functions, Formats, and Uses

Since the start of this thesis effort, many papers have appeared on dataloggers, their design, and their uses. This section describes the most commonly suggested datalogger functions and compares them to our concept of a DIS VCR.

2.4.1. Datalogger Uses. In some forms of training, it is more desirable to place the trainee into mission scenarios that can be repeated exactly, rather than injecting the interactive variability of DIS simulations. In any simulation, reactions of participants can vary, making accurate measurements of performance impossible. Guckenberger, and others, suggest using a "logger-playback module" to set up specific training scenarios. A single person could create the missions by recording the actions of one simulator, playing that logged simulation back while running another vehicle simulation that interacts with the first, and recording the two together. Each iteration adds another entity until the desired result is obtained for the training event. "The logger [or a DIS VCR] may be superior for simple interactive scripted training tasks" (7:263). More interesting is Guckenberger's suggestion to "convert JSTARS or AWACS data directly to a DIS logger file format." Analysts can then use a fast-scan replay mode and watch a "God's eye view of the battlefield" to detect patterns in enemy movements (7:267). Upon completion, the DIS VCR and RDT will provide the fast-scan mode and view for this purpose.

Burke and Lyou are interested in using a DIS VCR-like tool "to evaluate the network component's implementation of the DIS protocol." They want to know if applications are correctly following the DIS standard and if data integrity is maintained across the network (8:D58-D59). They want to isolate low-level network interface problems like corrupt data packets and perform high-level testing on applications for DIS compliance. They even suggest adding a packet editor so they can selectively alter the data to test application tolerances to certain errors.

The main use of the DIS VCR is remote debriefings. The logged Red Flag exercise will be replayed while mission situations are analyzed using RDT as explained in section 1.1.

2.4.2. Datalogger Functions. This section lists and describes all datalogger functions that are needed in RDT or were suggested by others. Table 2.2 summarizes the DIS VCR functions for RDT, as described in section 1.5.

Table 2.2. DIS VCR Functions for RDT

FUNCTION	PURPOSE
Record	Capture DIS PDUs to disk
Record Filtering	Capture only PDUs that match certain parameters (e.g. Entity ID, Exercise ID, Site ID, ...)
Replay	See individual functions below
Pause	Stop action to analyze particular moment
Fast Replay	Quickly scan events to reach particular actions/events
Fast Forward & Rewind	Quickly move to a moment in time
Slow Replay	Slow the action down to observe frame-by-frame developments
Play Filter	Replay a on different exercise ID than recorded
Keep Header Data	Identify recordings.

Guckenberger, and others, want a datalogger to detect the kill of a scripted target, then filter out any further PDUs from that entity or play a destroyed entity PDU on each update (7). This could be done while recording or replaying and would require much overhead in maintaining a state-of-the-world structure. This function is outside the scope of dataloggers and would be a separate application that can read the datalogger file format (see formats in section 2.4.3) and handle PDUs for probable kills.

Burke and Lyou want the same functions for logging, storage, playback, and flexible data subset selection as those for the DIS VCR (8:D-59). However, they also want a single-step mode that allows detailed examination of individual DIS packets for form and content and a way to measure the packet rates. They also said it is necessary to filter the replay output of PDUs to

allow analyses on specific sets of the logged data (8:D-60). Finally, they recommend packet editing tools that allow modification of the exercise ID, entity ID, or the introduction of specific errors in PDUs for application testing. Most of these new functions could easily be added to the DIS VCR design and playback filtering could be done using two VCRs. Although DIS VCR functions do not allow entity ID modifications, they do provide for exercise ID changes. Moreover, Burke and Lyou do not specify that the tools be built into one piece of software, and AFIT has other tools that can examine PDU content for data integrity.

The DIS VCR is designed with the functions needed for remote debriefings and could be adapted for other uses. Table 2.3 lists the additional functions not covered by the scope of this thesis.

Table 2.3. Datalogger Functions Suggested by Others

FUNCTION	PURPOSE
Kill scripted targets	Realism in training with repeatable scenarios
Single-Step Replay	PDU packet analyses
PDU Editing	Change IDs or inject errors
Display PDU Rates	Network traffic versus data integrity analysis

It is clear that datalogger designs are driven by the specific needs of the user. Therefore, a common datalogger file format, like those discussed in the next section, will allow DIS users to share data and tools.

2.4.3. Datalogger Formats. DIS development is being pursued by various organizations. Many tools for DIS analysis and visualization have been built, but they require the logged data to be in their specific format. To share tools that use PDU logged data, we need to develop a standard way of storing that data. This section examines two different approaches to standardization.

2.4.3.1. Green's Standard Datalogger Format. Green states that "a standard header, in conjunction with a standard data analysis file format, would facilitate the sharing of information and tools" (9:546). Table 2.4 contains the fields he recommends, the number of bytes each field uses, and a rationale for the fields. Green's standard header is not the minimum needed, which he suggests by identifying the bold-shaded fields as "mandatory" (9:551). Many of Green's fields are used when logging frames rather than DIS PDUs. Frames are captured to do network analysis or to record non-DIS data; actions which are not applicable to our DIS PDU datalogger.

After the header comes a block he calls the D-Record that contains D-Packets (9:553). Figure 2.6 shows the layout of this structure. The D-Structure allows the programmer to read a block of PDUs rather than one PDU at a time, thereby speeding up disk I/O. The structure could be read into memory, then parsed in a loop to send PDUs. The D-Packet allows for variable length PDUs, stopping when the D-Record is full. A PDU count field should be added to the D-Record header and used to set loop variables. Green suggests a D-Record block size of 240k-bytes which would hold about 1460 entity state PDUs.

D-RECORD		
Length	4 bytes	Total fixed block (D-Record) size
Start Time - First D-Packet Time	8 bytes	UNIX stamp
Stop Time - Last D-Packet Time	8 bytes	UNIX stamp
D-Packet 1	D-Packet Size	Multiple of 8 bytes
:	:	:
D-Packet n	D-Packet Size	Multiple of 8 bytes
Padding	m bytes	To next 8-byte boundary
D-PACKET(s)		
Previous D-Packet	4 bytes	File index pointer for reverse play
PDU Type	2 bytes	Enumeration (i.e. DIS, SIMNET)
Time Stamp	8 bytes	UNIX stamp
PDU Length	4 bytes	From the PDU captured
The DIS PDU	PDU Length	Last field
Padding	Bytes	To an 8-byte boundary

Figure 2.6. The D Structure for a PDU Block

Table 2.4. Green's Standard Header Format (9:547-551)

FIELD	BYTES	TYPE	REASON
Logger Name Constant	16	Char	To locate lost data files with a find utility
Logger ID	2	Unsigned short	Identify internal sub-format
Logger Revision	2	Unsigned short	Identify internal sub-format
Logger Site ID	2	Unsigned short	To combine files from different sites.
Logger Host ID	2	Unsigned short	To combine files from different sites.
Header Length	4	Unsigned short	Header length in 8-byte double words
Size of Successive Records	4	Unsigned long	Fixed length of D-Records (see discussion)
Machine Name	64	Char-UNIX style	To combine files from different sites.
Logger Machine Name	96	Char	To combine files from different sites.
Logger Information	2048	Future use padding	Might be used later
Test ID	128	Char	ID which test was logged
Trial ID	128	Char	ID which trial of the test it was
TimeZone - Real World	8	UNIX tz structure	These fields identify the actual time of the recording and a different simulation time.
Start Date/Time - Real	8	UNIX timeval structure	
Stop Date/Time - Real	8	UNIX timeval structure	
TimeZone - Sim World	8	UNIX tz structure	
Start Date/Time - Sim	8	UNIX timeval structure	
Stop Date/Time - Sim	8	UNIX timeval structure	
Data Link Protocol	1	Unsigned char	Information about the data for the analyst
Network/Transport Protocol	1	Unsigned char	No reason given
Padding	2	Unsigned char	No reason given
Fixed Cell Size	4	Unsigned long	If using fixed-length cells instead of frames
Logger Data Link Address	64	Unsigned char	Ethernet address - no reason given
Logger Network Address	64	Unsigned char	IP address - no reason given
Transport Address	4	Unsigned long	UDP port - no reason given
Padding	4	Unsigned char	
Original File Name	256	Char	Hey it might be useful - no real reason
Command Invocation	256	Char	ID special settings on logger
Name of Terrain File	256	Char	So an application can use the same terrain for replay
Extra Terrain Information	256	Char	No reason given
Number of Dropped Packets	4	Unsigned long	Used when anomalies show up in analyses. Doesn't mention how to get this data.
Number of Collisions	4	Unsigned long	
Number of Giants	4	Unsigned long	
Number of Runts	4	Unsigned long	
Number of Auxiliary Files	1	Unsigned char	
Padding	1	Unsigned char	No reason given
Exercise ID	2	Signed short	A particular ID or -1 for all exercises
Padding	4	Unsigned char	No reason given
Each Aux. File Code	1	Unsigned char	For associated files like audio or the next volume if files are broken up.
Each Aux. File Name	255	Char	
Padding	To 24k	Bytes	Round header size to an 8-byte boundary.

2.4.3.2. Juliano's Standard Datalogger Format. A simpler standard file header is suggested by Juliano and has the following general requirements:

- Portability and compatibility
- Files must be readily identifiable
- Support real-time playback
- Minimize file space
- Assure accurate analysis of DIS-based war fighting

The first one means a standard file format like UNIX or DOS with DIS compatible data values.

To make files identifiable, he adds a character string of 256 bytes. Real-time playback is supported using a relative time stamp, which is the elapsed time since receipt of the previous PDU. He also adds date and time fields that would be useful to applications that display models according to seasons or time-of-day. To minimize the file size, variable length records are used to store PDUs. This adds a length field and a back pointer to the previous PDU record for bi-directional replays. Finally, he adds an IP address from the incoming packet to identify which machine the data originated from (10:128). The PDU record format is shown in Table 2.5.

Table 2.5. Juliano's PDU Record Format

FIELD	DATA TYPE
Relative Time Stamp	32-bits with microsecond resolution
Time/Date Stamp	32-bit Ctime with date and time to the sec
Machine Address	32-bit IP address
Previous PDU Length	32-bit integer, acts as pointer
Current PDU Length	32-bit integer
The PDU	Current PDU Length

For some uses, this may not be enough information; however, it makes Juliano's datalogger independent of the architecture. In the last section, Green's logger stored the entire Ethernet frame and used it for low-level network analysis. Keeping a datalogger at the DIS level (just PDUs) allows network interface improvements independent of any DIS logger application (10:129).

The format of Table 2.5 is not efficient when it comes to disk I/O. It only allows programmers to read one PDU at a time. This means time for disk access is added as overhead for each replayed PDU.

2.5. Other-Than-Real-Time Simulations

"As the breadth of distributed applications expands, there are sufficient reasons to suggest that execution of distributed simulators should be permitted to take place in either a faster than real time or slower than real time mode" (11:223). Miller is not the first to suggest this concept, but was the first to present a partial solution that is compatible with DIS standards.

The key to other-than-real-time simulations is time scaling using a simulation clock that has adjustable speeds. The scale is a ratio of elapsed simulation time over "wall clock time" (11:225). The scale is used in applications to adjust dead-reckoning algorithms and modify when entities should be dropped due to inactivity. The time scale must be communicated to other applications and Miller suggests using a new PDU scale field or a separate simulation management PDU. With the appropriate modifications to applications and a way to notify them of time scale changes, other-than-real-time execution is possible.

2.6. Summary

With an appropriately designed DIS datalogger or DIS VCR, the replay needs of RDT can be satisfied. Files must be readily identifiable and organized so that data can be read in blocks to reduce overhead. Time scaling is a promising technique for controlling replay speed and requires the datalogger to communicate the scale to other applications (especially RDT).

Chapter III presents the design for the DIS VCR and shows how these elements are combined to achieve the objectives set forth in Chapter I.

III. Design

3.1. Introduction

Chapter II shows that there are many ways to approach the design of the DIS VCR. While the DIS VCR has an obligation to support remote debriefing using RDT, the design presented here is independent of RDT which also allows the DIS VCR to be used for many of the tasks discussed in section 2.4.1. This chapter starts by examining the top-level design issues that affected design decisions. Follow-on sections discuss VCR design details and other constraints. Although the thesis scope did not include implementing them, designs to support variable-speed replays in unmodified applications and audio in any replay, are presented in sections 3.7 and 3.8.

3.2. Motivation for the Initial DIS VCR Design

This section lists and describes the design considerations that had a global impact on the DIS VCR design.

3.2.1. Trade-off Analyses. There were two approaches considered for implementing a datalogger that had slow and fast replay speeds; one requires the receiving application to be modified, the other does not. In the first approach, the application is modified to replace real-time with scaled-time in dead-reckoning algorithms and methods that determine when entities have dropped out of the simulation. The other method is to have the DIS VCR modify all PDU velocity and acceleration fields to fit the current time scale and ensure PDUs get sent out at proper intervals (see section 3.7). This second approach does not require the application to change, but it has some drawbacks. Applications that perform analyses based on entity velocity and acceleration vectors, would be useless since these values are artificially changed. This approach also adds considerable overhead to the play loop, limiting its maximum speed and entity capacity. For these reasons, we opted for the first approach and decided to modify applications that use the DIS VCR.

3.2.2. Design Constraints. Another factor limiting maximum speed and entity capacity, is the overhead associated with storing and retrieving PDU data to and from a hard disk. To be useful, the design must support PDU transmission rates for large numbers of entities. We could read or write one PDU at a time, or use blocks of PDUs to speed up disk I/O. If the block method is chosen, we must ensure the daemon buffers do not overflow while a disk access is occurring; otherwise, PDUs will be lost. Preliminary tests were performed which showed that reading and writing one PDU at a time is a disk I/O bottleneck (see 3.4.3.1); therefore, this method was not selected as the design for our storage and retrieval scheme. Section 3.4.3.2 shows how to prevent PDU losses when reading or writing blocks.

3.2.3. The DIS VCR in a Network Simulation. The primary function of the DIS VCR is to record and replay DIS simulations. This section covers its intended use and how these expectations affected our design.

3.2.3.1. Interaction with RDT or Other Applications. Sections 1.1 and 2.3, made it clear that the DIS VCR would have to support variable-speed replays and pause for RDT. Unfortunately, DIS applications like RDT were not built to handle pauses or speed variances. The RDT dead-reckoning algorithms assume the simulation is in real-time and have no way of handling variable playback speeds. In slow motion, the application would dead-reckon entities past their actual locations (entities would appear to jump backward on each PDU update) and it would drop entities due to the delay between updates. In fast motion, the real-time dead-reckoning algorithm would lag behind the replay and entities would leap forward on each PDU update. Therefore, it is necessary to modify the receiving application so it understands variable speed replays.

3.2.3.2. DIS PDU Sources. The PDU time stamp presents a new set of issues. Old replay software, like RDT's *readred*, may send PDUs with the time stamps based on the original

recording time. Therefore, when capturing PDUs from any exercise, host, or site ID, the time stamps can differ dramatically; even for PDUs received nearly simultaneously. For example, a real-time simulation fills the PDU time stamp with local time while *readred* stamps its PDUs with range time. This creates a problem when time stamps are used to schedule the release of recorded PDUs in the play loop.

One solution is to store a receipt time with every PDU and use it to time-release PDUs. This adds system calls to the overhead associated with every PDU and limits the DIS VCR's recording capacity. On the other hand, if the old replay application sends PDUs a little faster or slower than real-time, we need to use the PDU time stamps to control their release. Since this method would prevent the recording of a real-time interaction with a replayed scenario, the solution that stores the receipt time with each PDU is used in the DIS VCR design.

3.2.3.3. Recording Demos Track-by-Track. Setting up a complex DIS simulation demo requires a substantial commitment of personnel and computing resources. However, with a DIS VCR, you could record demos one track at a time. Each track could involve multiple simulators that would interact with a replay of previously recorded tracks. As suggested in the last section, we store the receipt time with each PDU and use it to time-release all recorded PDUs.

3.2.4. Variable Speed with A Simulation Clock. Section 2.5 discussed the idea of time scaling to control other-than-real-time simulations. In section 3.2.1 we identified the advantages of scaling time. To carry out this idea, we introduce a variable speed simulation clock. We control our simulation clock with the system clock to maintain an accurate scaling factor. To solve the dead-reckoning problem above, the rendering application and the DIS VCR each use a simulation clock. The time from the simulation clock is integrated into the rendering application's dead-reckoning algorithms to correct the lead-lag errors. To use the same time scale as the DIS VCR,

there must be some way of communicating the current scale value when it changes. Section 3.5.2 describes how this is accomplished.

3.3. *Simulation Clock Design*

This section discusses the functions of a simulation clock and what is required to make time scaling work.

3.3.1. Functions a Simulation Clock Must Support. To support applications that render a scene based on the date, time of year, or time of day, the simulation clock must maintain and utilize date and time fields. As simulation fidelity matures, these will be needed to properly render lighting conditions, seasonal terrain appearance, and weather factors. Since the replay requirement includes variable speeds, the simulation clock has to have a way to scale the speed of the clock. Finally, we need a way to format the time for display in applications or the DIS VCR. Table 3.1 lists and describes the basic simulation clock functions.

Table 3.1. Simulation Clock Functions

FUNCTION	DESCRIPTION / USAGE
Set Simulation Time	Allows the simulation clock to start from any time.
Get Simulation Time	Returns the scaled simulation time. If scale is set to 1.0, it acts like a normal clock.
Set Simulation Date	Allows applications to use any date within the limits of the operating system. For UNIX, this is 1 Jan. 1970 to the year 2038.
Get Simulation Date	Returns the date set with Set Simulation Date.
Change Time Scale	Varies the speed of the clock

3.3.2. Time Since the Beginning of the First Simulation Day. To facilitate the design of scaled time, it is best to represent simulation time as time since the beginning of the first simulation day. This provides a way to easily gauge how much time has past between calls to the clock. More importantly, it allows us to set the clock to any date and time, and advance it by scaling the time difference between clock calls. Section 3.5 discusses how scaled time is used.

3.4. Recording

The user typically only gets one shot at recording a complex simulation exercise. This makes it important to design the record function so that no PDUs are missed. Therefore our goal was to shift as much overhead as possible to the replay function. The following sections describe the essentials of the recording design with emphasis on maintaining an efficient record loop.

3.4.1. Net Interface Design. To record DIS PDUs, it is necessary to communicate with the network. The DIS VCR uses standard AFIT network daemons to retrieve PDUs. The daemons extract the PDUs from the Ethernet frames and deliver them in buffers. The VCR copies each PDU, stores it, and marks the buffer empty so the daemon can fill it with another PDU.

3.4.2. File Header Information. One of the general datalogger requirements from section 2.4.3.2, is that files be readily identifiable. To satisfy that requirement, Juliano (10) used a 256 byte character field. However, the user may fail to enter sufficient information in the field. Also, if the DIS VCR is modified to support multiple versions of the DIS standard, then a separate field must be included so replay can select the appropriate algorithms for that version. We include fields for the user name, exercise ID, a title, DIS version, date, flags for each PDU type captured, and start and stop times.

3.4.3. The Storage and Retrieval Scheme. Designing a record function that is fast enough to prevent the loss of PDUs while providing an efficient way for the replay routine to retrieve the data and control it for replay functions, was a challenging task. This section identifies the difficulties and presents solutions to them.

3.4.3.1. One PDU at a Time Design. To conserve disk space, the best storage approach is to write PDUs one after the other following the file header. Then on replay, the PDU length field is used to determine the correct amount of data to read from disk and to maintain the file pointer position. However, for a disk with a 12 millisecond access time, an 8 millisecond rotational latency, and a 500k-byte per second transfer rate, the storage of 1000 PDUs takes 20.4 seconds or 20.4 milliseconds each. This rate is clearly unacceptable in our environment where typical PDU rates exceed 500 per second.

3.4.3.2. The PDU Block Approach. Handling a single PDU at a time is easier to implement, but the disk bottleneck almost guarantees that data will be lost. A faster approach for I/O is needed. Therefore, we chose to read and write blocks of PDUs. To simplify the block design, each block is structured with a start and stop time, an array of PDU pointers, the PDU array, and a PDU count field. The rest of this section outlines the block I/O approach and presents a comparison of it with the single PDU method.

The DIS VCR marks the daemon buffers empty when they are transferred to the block structure. While the VCR writes a full block to disk, it is possible for all of the daemon buffers to become full, resulting in PDUs losses. To prevent this from happening, two blocks are used in the producer-consumer parallel scheme shown in Figure 3.1. In the producer-consumer relationship, PDUs are inserted into a block until the count reaches a preset maximum. The block is

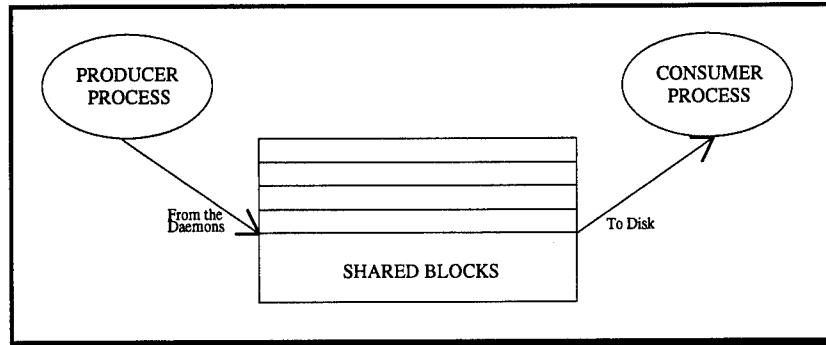


Figure 3.1. Record's Producer-Consumer Parallel Process Threads

marked full (a semaphore flag) and blocks are swapped so one can be written while the other is filled. This significantly increases the number of entities the record loop can handle.

As an example of the efficiency we can achieve with blocked I/O, consider the following calculation. A block of 1000 PDUs is about 150k-bytes and for a disk with a 12 millisecond access time, an 8 millisecond rotational latency, and a 500k-byte per second transfer rate, the write will take 0.32 seconds; 64 times faster than the single PDU approach. Furthermore, without a spawned consumer process, under a load of 1000 PDUs per second, 100 daemon buffers will overflow in 0.1 seconds or less (some buffers may already be filled) resulting in the loss of over 200 PDUs for each write to disk. If the disk is located on the network, instead of residing locally, the losses will increase.

3.4.4. Filtering the Input. There are times when the user wants to isolate a specific exercise, entity, or range of entities. Additionally, the user may only want to record PDUs from a particular site or host. In some applications, it is desirable to capture only one or two PDU types. For example, the user may want to see only the fire and detonation pairs or needs to isolate the audio. The DIS VCR design was built to accommodate the filtering of input PDUs based on any of the above criteria.

3.4.5. Record Pseudo Code. The record function that takes PDUs from the network and stores them to disk is shown below in pseudo code.

Pre-processing Steps

Spawn the two-thread producer-consumer process

Get information for the file header

Start the simulation clock

Recording Loop

While not done

Get a PDU from the daemon and store it if keeping

Store the receipt time with the PDU and write a value to the pointer array

Update the display

Mark the daemon buffer empty

If the block's count = MaxCount or the block has been filled, mark it full and swap blocks

(the consumer detects the full condition and writes the block to disk, then marks it empty)

End While

End Record Loop

Write the last block to disk

Post-process the file

End Record

The record loop uses the simulation clock to update the displayed clock so that two formatting routines are not needed; one for record using a real-time clock and another for replay which must use the simulation clock. This also makes it convenient for storing simulation time in file headers and block structures.

3.5. Playback

3.5.1. Net Interface Design. To replay DIS PDUs, it is necessary to communicate with the network. The DIS VCR uses standard AFIT network daemons to send the PDUs. The daemons insert the PDUs into the Ethernet frames and deliver them to the network. The VCR copies each PDU from the block structure to a daemon buffer and marks the buffer full so the daemon will send it.

3.5.2. Replay With a Simulation Clock. The simulation clock is used to control replay functions by means of scaling. When the scale of the simulation clock changes, that change must be communicated to all modified applications using the DIS VCR for replays. The following sections discuss the mechanism for communicating scale changes and how a change in scale affects each replay function.

3.5.2.1. A New PDU for Replays. Since the DIS standard was developed for real-time interactive simulations, it does not provide a means for controlling variable speed replays. Our design introduces a Replay PDU for this purpose. This PDU supports the following actions:

- Switch mode to PLAY, PAUSE, or STOP
- Update the simulation clock time or date
- Change the time scale
- Initialize, start, or stop the replay

Whenever the DIS VCR changes mode, time or speed, it transmits a Replay PDU on the network to report the change to receiving applications. The Replay PDU uses the same header described in section 2.2.1 and the fields necessary to carry-out the actions listed above. These actions are captured in the replay state diagram of Figure 3.2 and are described in subsequent sections. As

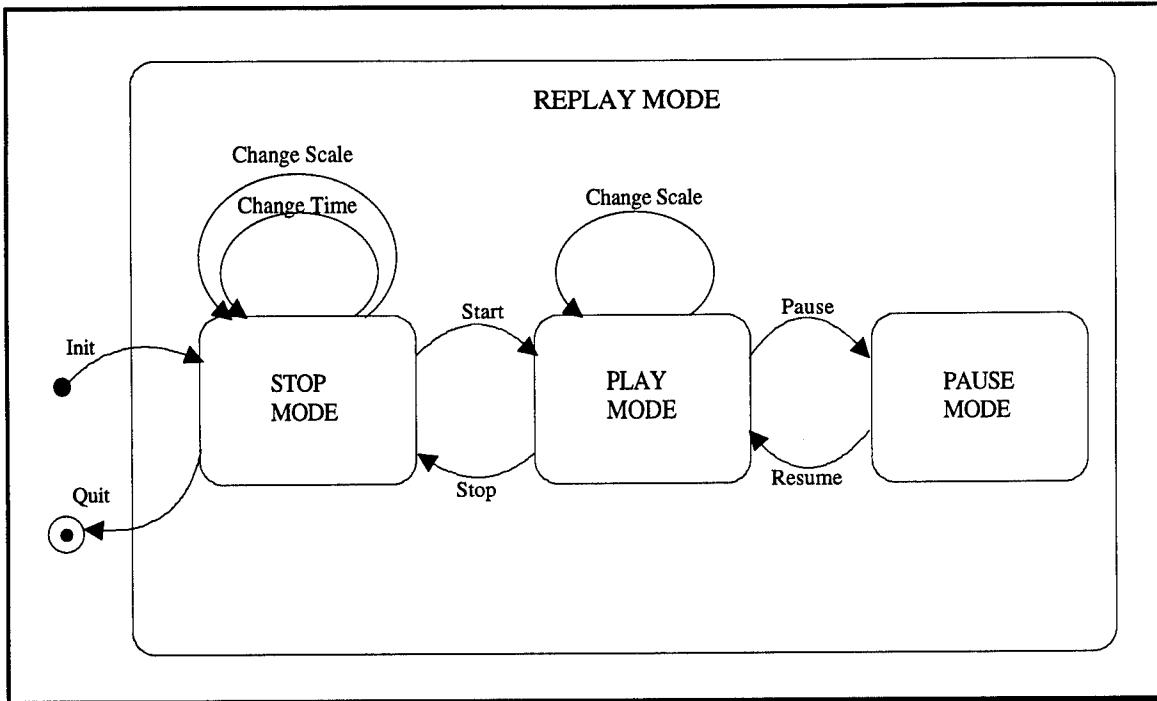


Figure 3.2. Replay State Diagram

depicted, replay initialization is what signals the application to start using its simulation clock instead of the system clock. The terminal condition (a circle with a dot in it) causes the application to revert back to using the system clock.

3.5.2.2. Variable Speeds. When the user selects a new speed, the DIS VCR sends out a Replay PDU to change the time scale. This can be done from the STOP and PLAY modes as shown in Figure 3.2. The VCR displays the new speed, sets its simulation clock speed to the new value, and begins releasing PDUs accordingly. The receiving application's dead-reckoning and entity time-out algorithms use the new scale to control their activities.

3.5.2.3. Pause. When pause mode is selected, a Reply PDU is sent to signal a mode change. The DIS VCR sets the simulation clock scale to zero which freezes the PDU stream at the

current point in the PDU block. The receiving application is responsible for keeping entities in its current player list alive and in their last position until a resume Replay PDU is received.

3.5.2.4. Applications and Replays. Because there is always some network delay before the application receives the Replay PDU that sets the initial clock time or changes the time scale, the DIS VCR replay and the receiving application will be out-of-sync. To illustrate, assume the DIS VCR and modified application are at ten times normal speed when the user decides to change speed to one tenth of standard (slow motion). The VCR sends out a Replay PDU to inform the application of the change, then responds immediately to the change and stretches the time between PDU releases 100-fold. The application continues to run at the faster speed until it gets the Replay PDU, entities leap backward on updates and begin dropping off because hundreds of PDUs were expected and only a few were received. Unfortunately, there does not seem to be a workable solution to this problem.

3.5.3. Play Loop Pseudo Code. The play function that takes PDUs from the disk and re-transmits them across the network, is shown below in pseudo code. The user may change speeds and pause while inside play's PDU block loop.

Pre-processing Steps

Select a file

Set the simulation clock with file header

Spawn the two-thread producer-consumer process that gets data from disk

Start the DIS VCR simulation clock

Fill and send an initialization Replay PDU

End Pre-processing Steps

Outer loop

*While Not stopping and Not end-of-file
Hold for full PDU block*

PDU Block Loop

While Not stopping and Not end-of-block or end-of-file

If in PLAY mode

While PDU time Not equal to simulation clock time

Check user input, respond to STOP, PAUSE, and speed changes

End While PDU time Not equal to simulation clock time

Send current PDU

Update display

End if PLAY mode

Else PAUSED

If resume then

Send mode-change Replay PDU

Restart simulation clock

End if resume

End Else PAUSED

End While Not stopping and Not end-of-block or end-of-file

End PDU Block Loop

Swap PDU blocks

End While Not stopping and Not end-of-file

End Outer loop

Post-processing Steps

Kill the producer process, it is no longer needed

Send STOP mode Replay PDU

Reset data file

End Post-processing steps

3.6. The DIS VCR Interface Design

A well thought-out human-computer interface can make a substantial difference in a user's learning curve, performance, error rate and satisfaction. The first step in good human-computer interface design is to determine the required functionality. Exactly what are the tasks and sub-tasks that need to be done? The most frequent mistake by new designers is to add too much functionality. This just increases program complexity and clutter which, among other things, increases the learning curve and decreases user satisfaction. The second step is to ensure reliability, security, and integrity (13:57-164). The functionality of the DIS VCR was determined by examining the RFMDS features the VCR is suppose to emulate as discussed in section 2.4.2. The DIS VCR design addresses reliability, security, and integrity by using an interface design that limits many of the errors the user could make.

There are also some underlying design principals to consider for most interactive systems and especially when novice users are involved. First of all, the interface should maintain consistency by using the same prompts, menu styles, and help screens, all of which should keep a similar layout. The interface gives users informative feedback for every user action; even simple tasks get a nominal message that shows completion (13:61). The DIS VCR interface design is structured for a consistent approach to communicating with the user.

To keep from overwhelming the user, we have avoided packing too much information or too many actions into a single screen. The DIS VCR interface design breaks up tasks into several sequenced, well organized screens that keep a similar layout between them. This strategy reduces user search time and increases productivity and task speed (see section 3.6.2).

3.6.1. DIS VCR Interface Goals. The main theme for the DIS VCR interface is simplicity. Its basic functions should be as easy to use as the common home VCR that plays VHS tapes. If the user has to remember a lot of command line parameters to perform a simple replay, the interface design is a failure. The following list summarizes the design goals for the DIS VCR:

- Reduce the interface learning curve
- Maximize task speed
- Minimize the user error rate
- Easy access to help
- Easy Recording Identification

3.6.2. Interface Styles. Choice of interface interaction components depends on the target user and the goals we set for the interface. The list below, shows some of the primary interaction styles.

Table 3.2 lists these style types and describes good and bad aspects of each.

- Menu selection
- Form fill-in
- Command language
- Natural language
- Direct manipulation (pointing device)

Table 3.2. Interface Style Types, Pros and Cons (13:57-60)

TYPE	ADVANTAGES	DISADVANTAGES
Menu selection	Shortens learning, structures decisions & easy error handling	Slow, takes screen space
Form fill-in	Simplifies data entry, little training needed	Takes screen space
Command language	Flexible, appeals to Power users, can use the power of macros	Poor error handling, requires a lot of training and memorization.
Natural language	Known syntax	A lot of keystrokes to enter cmds and its behavior is unpredictable.
Direct manipulation	Visually presents task concept, easy to learn & retain, high satisfaction	Hard to program & more hardware needed.

Based on the interface design goals of section 3.6.1 and the advantages listed in Table 3.2, the best combination for the DIS VCR interface is a pseudo-menu selection type form that is operated with direct manipulation and where data is entered via the form fill-in style. The pseudo-menu selection form functions can primarily be represented by buttons that can be pushed with a mouse. As suggested by Foley (17:457) and Shneiderman (13:71), these forms are broken into several sequenced, well organized screens as shown in Figure 3.3. The larger ones overlay the main VCR screen to focus the user's attention to a particular task. The message forms are dialogs that pop-up to give the user relevant feedback like task completion or information on detected errors. What the user manipulates on these screens or forms is the subject of the next few sections.

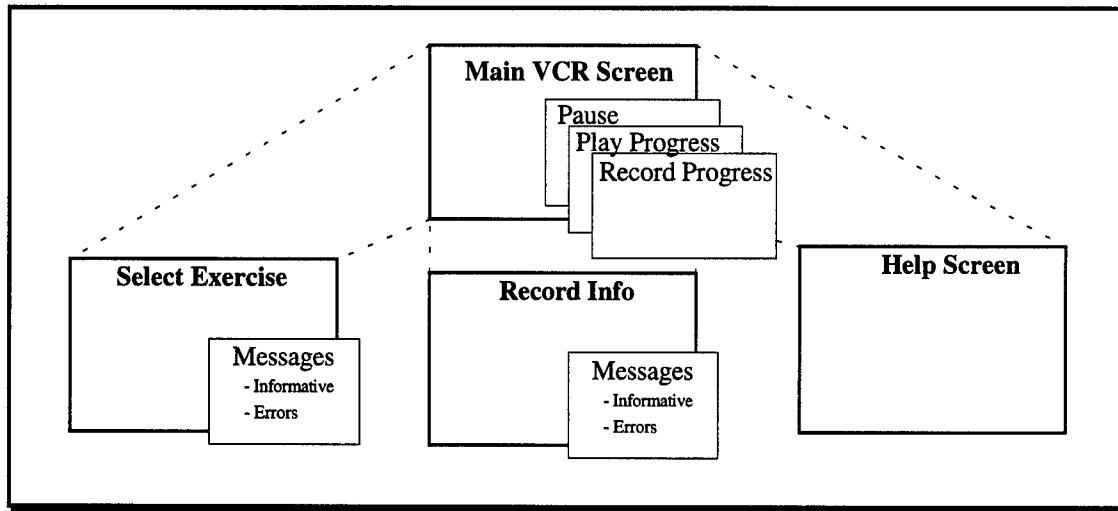


Figure 3.3. DIS VCR Screen Layouts

3.6.3. Using High-level Interface Building Tools as a Basis. Table 3.2 points out that direct manipulation is difficult to program. We intend to use high-level interface tools that reduce the difficulties to a manageable level for the DIS VCR interface. Users benefit since high-level tool developers take a standardized, rational approach to screen design that allows applications to acquire a familiar look and feel. These tools usually benefit from years of experience and usability testing (14:3).

3.6.3.1. A High-Level Interface Tool Set. The following sections describe elements of high-level interface tools that are used to design the DIS VCR's interface.

3.6.3.1.1. Basic Tools the VCR Needs. The building blocks of the interface are 3-D buttons, value adjusters like sliders, counters, input fields and text. These simple objects, shown in Figure 3.4, can be combined to create a powerful, easy to use interface.

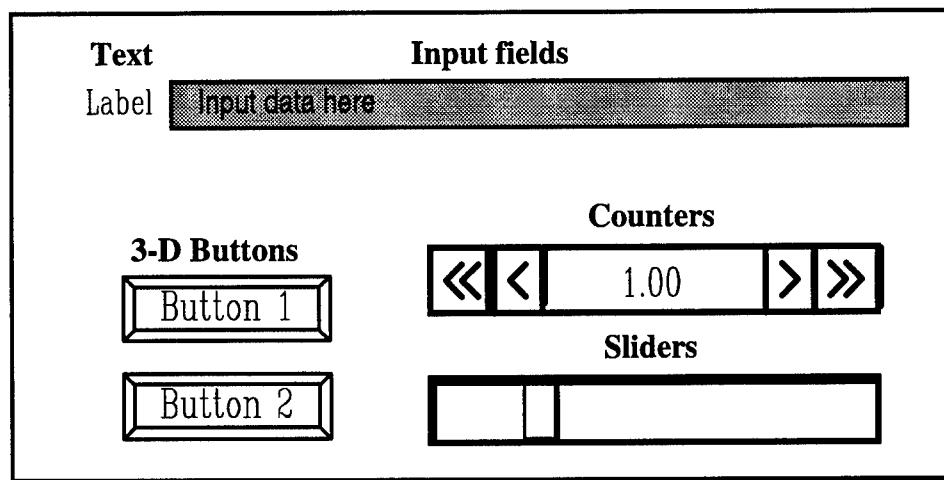


Figure 3.4. Interface Building Blocks

3.6.3.1.2. Special Objects. As effective as they are, the building blocks of Figure 3.4 are not enough by themselves for the DIS VCR interface. To reduce the manipulations for specifying which file to replay, a selection pick-list is convenient. With this type of object, the user is presented with a list of the items of interest and only needs to point and click to select one. Figure 3.5 shows a basic pick-list with one item selected. Pick-lists can be programmed to select one or many items and can list the item in any specified order.

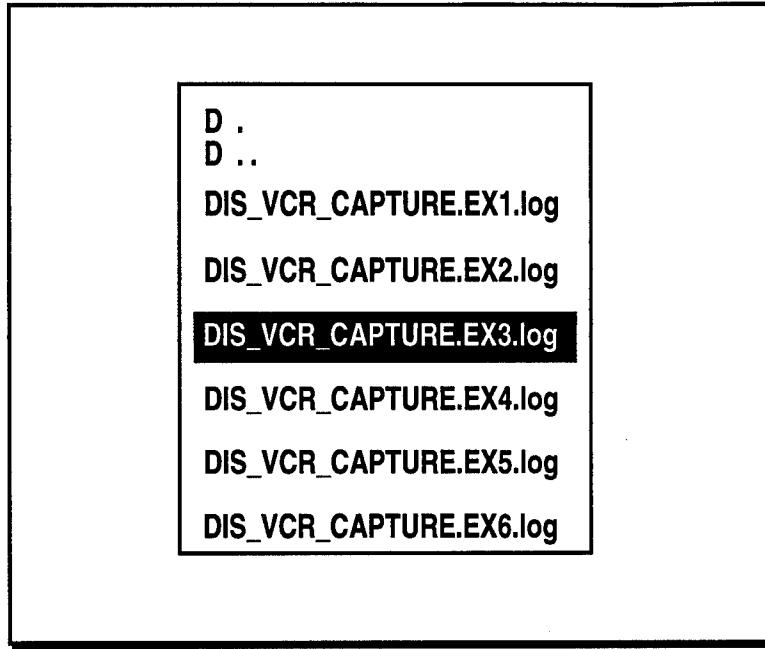


Figure 3.5. A Basic Pick-List

3.6.3.1.3. Events. Manipulation of the interface objects should create user events that can be used by the program. These events tell the application which object was used so the application can choose the appropriate action to take. The event detection process must not interrupt the program so that active tasks can continue their functions.

3.6.4. The Main VCR Form Design. The main screen must provide access to all of the DIS VCR's functions shown in Figure 3.3. Therefore, it must contain the interface objects needed to start a recording, initiate a replay, or control the current replay. To meet the interface goals of reducing the learning curve and easy access to help, the main DIS VCR screen design should be modeled after a typical home VCR (that interface is familiar to many users) and should provide a single-step access object for help.

3.6.4.1. Speed Controls. Standard speed settings give the user a convenient way to choose from among several common choices. This can be accomplished with special objects called

radio buttons. These buttons are grouped together in one cluster where the user can select only one of them. An example of this object group is shown in Figure 3.6. To capture speeds between the discrete values, we can use slider and counter objects like those in Figure 3.4.

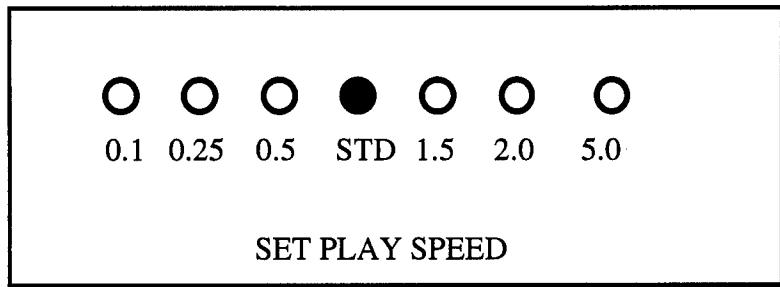


Figure 3.6. Radio Button Object Group

3.6.4.2. Displayed Information. The main DIS VCR screen should display information about the current recording to the user. The information must allow the user to determine which PDUs are being replayed, the date and time range when it was recorded, and what the recording is of. The main screen must also provide user feedback that indicates replay progress and clearly identifies where they are in the playback.

3.6.5. Record Form Design. To simplify data entry and reduce the user's error rate, the file header information should be captured via the form fill-in style. Record form entries must include user name, exercise ID, a title, a file name, and which PDUs to capture. Error checking should ensure that the user specified a file name and at least one PDU type to capture. The form should allow users to enter an exercise ID to specify the simulation they wish to record. The form must include a way for users to cancel the record process and return to the main screen. In addition, the form should provide a single-step access object for help.

3.6.6. Select Exercise Form. The selection form should give users an easy convenient way to select and load data files for replay. For file selection, an object like the pick-list in Figure 3.5 can be used. When the user selects a file, its information should be displayed so the user can identify the recording. The information should be identical to that entered in the record form. After selecting a file, the user must have some way to either delete the file or load it for replay. Error checking should ensure that the user chooses a file created by the DIS VCR. Like record, this screen must also have direct access to the on-line help.

3.6.7. Other Screens. Other screens include messages, questions, pause/resume, play progress, and record progress. Messages, questions, and progress dialogs provide informative feedback to the user and signal task completion. For example, when the user pauses a replay, a pause dialog should pop-up and provide an interface object that lets the user resume the replay.

3.6.8. Interface Summary. Now that the DIS VCR functionality, screen layout, and interface components have been specified, interface implementation can proceed. The implementation details are found in Chapter IV along with a discussion of our choice of high-level interface programming tools and their applicability to our design.

3.7. Supporting Unmodified Applications

This section presents design changes for the DIS VCR that will allow it to support applications that are not modified to use a simulation clock and Replay PDUs. It may be that the application is built into hardware which cannot easily be modified, but could use the services of a variable speed replay application like the DIS VCR.

3.7.1. Special Design Considerations. A typical DIS rendering application maintains a State-Of-The-World (STOW) for all active entities in the simulation. The current state is used on each frame to correctly position and orient the entities based on PDU updates and dead-reckoning algorithms. The state is maintained with calculations that use the local system clock and the entity's velocity and acceleration vectors to predict where the entity should be on each iteration. Therefore, to get the appropriate response to a slow or fast motion replay without an adjustable simulation clock, adjustments to entity velocity and acceleration vectors are required.

3.7.2. Slow-motion Replay or Pause. Most DIS applications (i.e. RDT) are not built to handle pauses or speed variances. The dead-reckoning algorithms they use assume the simulation is in real-time and have no way of handling variable playback speeds. In slow motion, the application would dead-reckon entities past their actual locations (entities would appear to jump backward on each PDU update) and it would drop entities from the simulation due to the delay between updates.

To prevent entities from dropping out of the simulation in slow motion or pause mode, the DIS VCR must ensure PDU updates are sent out every five seconds as prescribed by the DIS standard (2:25). This requires the VCR to maintain its own dead-reckoned STOW.

3.7.3. Maintaining State-Of-The-World. DIS applications that maintain a STOW do not keep all of the information from the PDUs since they generally do not have to re-transmit them onto the network. The DIS VCR must keep all of the PDU information since it does transmit it back onto the network. The structure shown in Figure 3.7 holds the PDU, the elapsed simulation time since its last update, and the elapsed system time since the last time a PDU was broadcast for this entity. The elapsed simulation time is used to determine when an entity should be dropped from the active STOW list. The following sections discuss the DIS VCR actions in fast and slow replay modes.

FIELD	DESCRIPTION
PDU	A full PDU
Elapsed Simulation Time	Simulation clock time
Elapsed System Time	Real-time

Figure 3.7. STOW PDU Record

3.7.3.1. Slow-motion Loop. On each slow-motion loop iteration, the STOW PDUs are updated by dead-reckoning them with the simulation clock time and the entity velocity and acceleration vectors are modified to match the simulation clock time scale. Also, any PDU that has exceeded five seconds of elapsed real time, is broadcast onto the network. These actions are integrated into the play loop as shown in the pseudo code in section 3.7.4.

3.7.3.2. Fast-motion Loop. The fast-motion loop ignores the STOW since PDU updates are sent at faster than normal rates. The only thing the fast-motion loop does is modify the entity velocity and acceleration vectors to match the simulation clock time scale. However, special actions occur on each speed change for both slow and fast replay, as discussed in the next section, that requires the DIS VCR to keep an active entity structure even for fast-motion replays.

3.7.3.3. Speed Changes. If the user changes speeds, the DIS VCR must send a burst of all active entity PDUs with the new scale adjustment. If this is not done, application dead-reckoning will not match the current scale and will provide inaccurate results. Since the burst of adjusted PDUs is not instantaneous, there will be some noticeable lag in the application. Also, the burst will interrupt the sending loop and PDU updates will need to catch up to the simulation clock. After this brief settling time, the application rendering will appear smooth again. The modified play loop in section 3.7.4 shows how speed changes are handled.

An alternative to the PDU burst in fast-motion replay, is to let the entity's velocity and acceleration vectors be updated as they arrive in the input stream. The application settling time

will vary with the DIS VCR speed and total active entity count. During this settling time, relative velocities between updated and non-updated entities will be greatly distorted.

3.7.4. The Modified Play Loop. The following pseudo code is a reiteration of the play loop with the new modified portions appearing in italic bold print.

Pre-processing Steps

Select a file

Set the simulation clock

Spawn the two-thread producer-consumer process that gets data from disk

Start the DIS VCR simulation clock

Fill and send an initialization Replay PDU

End Pre-processing Steps

Outer loop

While Not stopping and Not end-of-file

Hold for full PDU block

PDU Block Loop

While Not stopping and Not end-of-block or end-of-file

If in PLAY mode

Update or add entity to the STOW

Multiply PDU velocity and acceleration vectors by scalar

If slow-motion

*Broadcast adjusted PDUs for entities that have not had an update
 within 5 seconds of system time*

End If

While PDU time Not equal to simulation clock time

Check user input, respond to STOP, PAUSE, and speed changes

STOP: Set stop variable to drop out of loops

PAUSE:

Begin

Stop clock, set mode=PAUSE

Send PDU burst, velocities and accelerations set to zero

End

```

SPEED:
  Begin
    Change DIS VCR clock scale
    • Traverse STOW and send PDU burst with adjusted velocity and acceleration vectors.
    • send PDUs from the stream as fast a possible until even with the simulation clock.
  End
  Update whole STOW with dead-reckoning
End While PDU time Not equal to simulation clock time

  Send PDU
  Update display
End if PLAY mode

Else PAUSED
  If resume then
    Send mode-change Replay PDU
    Restart simulation clock
    Send PDU burst with adjusted velocity and accelerations
    Send PDUs from the stream as fast a possible until even with the simulation clock
  End if resume
End Else PAUSED
End While Not stopping and Not end-of-block or end-of-file

End PDU Block Loop

  Swap to next PDU block
End While Not stopping and Not end-of-file

End Outer loop

```

Post-processing Steps

```

Kill the producer process, it is no longer needed
Send STOP mode Replay PDU
Reset data file
End else

```

End Post-processing steps

3.7.5. Summary. Supporting unmodified applications takes considerable effort and adds an enormous amount of overhead to the replay loop. For large entity counts, replays other than slow-motion may not be possible. Also, analyses based on entity velocity and accelerations will not be valid at speeds other than normal.

3.8. DIS VCR Integrated Audio

The DIS VCR already includes a way to turn on the capture of signal PDUs that carry DIS audio. However, the current play loop implementation does not provide a means to play the audio. Section 1.1 stressed the importance of audio for realism in remote debriefings with RDT and said that the ability to monitor radio communications would be a significant step forward for the remote debriefing concept. This section outlines the design changes needed to provide real-time audio in DIS VCR replays.

3.8.1. Design Drivers. The biggest design issues are the length of time it takes to play digitized audio and the size of the data. We have demonstrated that dedicated audio hardware can capture Red Flag UHF audio, convert it to DIS signal PDUs, and broadcast it on a wide-area network. The same hardware can read signal PDUs off the network and play the audio using its built-in sound board. Therefore, our audio design is not concerned with how signal PDUs get to the DIS VCR.

3.8.2. Signal PDU Length and the Current VCR Design. The signal PDU data fields can expand its size to 1500 bytes; the limit set by the Ethernet frame (1:24). The length is much higher than the other PDUs of interest which are 144 bytes or less as was shown in Figure 2.2. This is not a problem since the DIS VCR PDU block design accommodates PDUs of any size and the interface allows users to select signal PDUs as one to be captured.

3.8.3. A Separate Process for Audio. The size of digitized audio data in a signal PDU makes it imperative to separate its replay from the replay of other PDUs. We can use the same producer-consumer relationship that we used for our PDU block I/O approach. When a signal PDU is encountered in the data stream from disk, it can be handed off to a parallel process that handles conversions and replays the extracted audio data while the DIS VCR continues sending other

PDUs. The DIS VCR fills an audio structure with the raw data and marks it full. The audio process detects a full condition and starts processing the data for replay. This process may include decompression of the data and formatting it for the audio program to use. This process is shown in Figure 3.8.

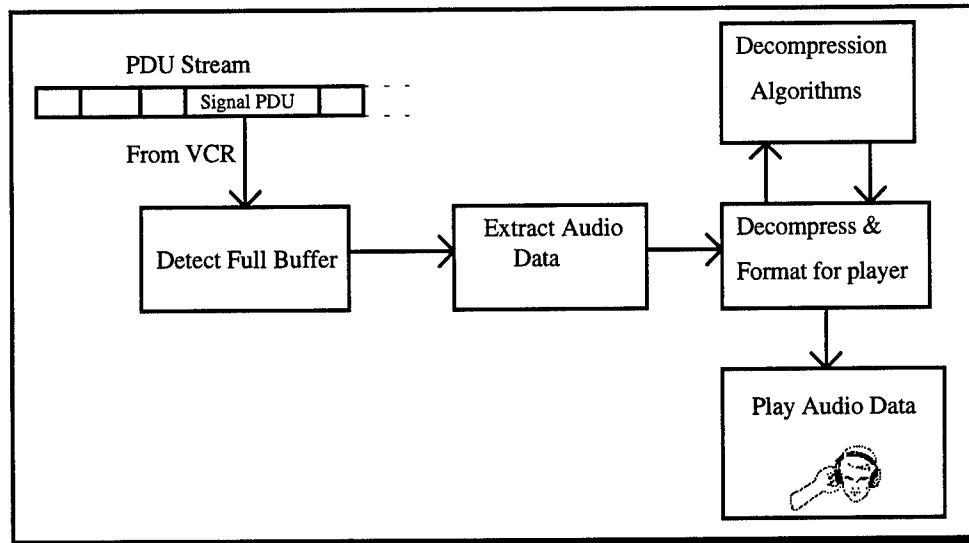


Figure 3.8. Audio Conversion Process

3.8.4. Audio Design Summary. Except for the decompression algorithms and formatting for a particular audio program, Figure 3.8 represents a complete design. The DIS VCR is already designed to capture signal PDUs and, with time, could be modified to include audio replay.

IV. Implementation

4.1. Introduction

Chapter III presented our design for record, variable speed replay, and the user interface that controls the DIS VCR system. This chapter examines the implementation of the DIS VCR functions and user interface design.

4.2. The Tools of Implementation

The standard AFIT network daemons are implemented in C and all AFIT applications using replay are written in C++. Also, the AFIT C and C++ development environment has mature programming tools including the public domain high-level Forms interface libraries selected for the DIS VCR implementation. Therefore, C and C++ were natural choices for programming the DIS VCR. This is especially true for the simulation clock which had to be integrated into the C++-based Remote Debriefing Tool (RDT) and Synthetic Battle Bridge (SBB) applications.

4.3. Simulation Clock Implementation

The simulation clock was on the critical path for DIS VCR implementation since the control of replays depended on it. The following sections describe how the clock was implemented to provide the needed functionality for both the DIS VCR and replay-modified applications.

4.3.1. Simulation Clock Functions. Table 4.1 lists and describes the simulation clock functions. These were coded as methods in a C++ class called `Simulation_Clock`. When an instance of `Simulation_Clock` is created, the clock date is initialized to 1 January 1970 and the time is set to midnight. These values are the lower limit imposed by the UNIX operating system. Although the C++ language provides UNIX compatible data types for the real time and date, we

needed special types to keep track of the simulation date and scaled time. The resulting time and date structures are shown in Table 4.1. The sim_time_t type is used for reporting time with a

Table 4.1. Simulation Clock Functions

FUNCTION	DESCRIPTION / USAGE
set_sim_time	Allows the simulation clock to start from any time using struct of type <code>sim_time_t { unsigned short sim_hour; unsigned short sim_minute; unsigned short sim_second;}</code>
get_sim_time	Returns the scaled simulation time. If scale is set to 1.0, it acts like a normal clock.
set_sim_time_double	Uses a double to set time in seconds since first simulation day
get_sim_time_double	Returns a double of seconds since first simulation day
set_sim_date	A date between 1 Jan. 1970 and 2038 represented by a struct of type <code>sim_date_t { int sim_month; unsigned short sim_day; unsigned short sim_year;}</code> Represents the first simulation day
get_sim_date	Returns the date set with Set Simulation Date.
change_time_scale	Uses a float to vary the speed of the clock
get_time_scale	Returns the time scale as a float

resolution of seconds. Since microsecond resolution is used in DIS application dead-reckoning and in determining the time release of DIS PDU packets, we use a double that represents the number of seconds (with 15 digit precision) since the beginning of the first simulation day. The precision of a 32-bit float is only accurate for six digits of resolution, so a double was required (15). The time since the beginning of the first simulation day, provides a method for determining when a recording crosses midnight and in calculating scaled time.

4.3.2. Scaled Time The simulation time is updated on every call to `get_sim_time` or `get_sim_time_double` by the following calculation:

$$\text{sim_time} = \text{last_sim_time} + \text{real-time since last call} * \text{time_scale}$$

where the real-time since last call is a system clock difference between the two calls. For example, if the simulation time is 12:33:59, `time_scale` is 10, and real-time passage was 1.0 seconds, then the new `sim_time` is 12:34:09.

4.4. Recording

The following sections describe the implementation of the recording design with emphasis on maintaining an efficient record loop.

4.4.1. File Header Information. The file header information that includes all of the fields specified in section 3.4.1 is shown in Table 4.2.

Table 4.2. File Header Information

FIELD NAME	SIZE (bytes)	TYPE / DESCRIPTION
simdate	8	A <code>sim_date_t</code> type (see Table 4.1)
name	26	A 26 character User Name
title	30	A 30 character title
PDU_flags	20	Array of 5 integer flags, shows captured ON/OFF
ex_id	4	An integer up to 65535
site	4	An integer up to 65535
DIS_version	4	An short int value of 3 indicating DIS Version 2.0.3
start_time	8	A double of seconds since 1st sim day
stop_time	8	A double of seconds since 1st sim day
PDU_count	4	Total PDUs in file, up to 4294967296 for unsigned int
num_blocks	4	Total number of PDU blocks stored

The DIS VCR writes a partially filled header to disk to reserve room for it. When recording stops, the program writes an updated header to that space.

4.4.2. The Storage and Retrieval Scheme. The storage and retrieval scheme implementation for the PDU block approach, was accomplished using the block structure shown in Figure 4.1.

FIELD NAME	SIZE (bytes)	TYPE / DESCRIPTION
start_time	8	A double of seconds since 1st sim day
stop_time	8	A double of seconds since 1st sim day
empty	4	Variable for communicating empty/full condition
version	4	Set to 1 for this DIS VCR version
count	4	Number of PDUs in this block
offset	4004	Array of pointers into the data char array for up to 1000 PDUs
data	152,000	Data array, can hold up to 1000 entity state, fire, and detonation PDUs

Figure 4.1. PDU Block Structure

There are actually 1001 offset pointers used in the block traversal algorithm. The extra pointer marks the end of the PDU character array when the maximum PDU count is reached and is used to determine the length of the last PDU as follows:

$$\text{Length} = \text{offset}[i+1] - \text{offset}[i]$$

The algorithm for traversal could have used the PDU length field to move forward through the character array, but this does not provide for future DIS VCR versions that may want to play the data in the reverse direction.

The start and stop times are used in the play loop to schedule the timely release of PDUs. The empty field is used to ensure that each block is ready to be written or filled, so a memory collision

does not occur. The record loop (the producer) uses a spin and wait loop to ensure the block has been fully written to disk by the consumer process before it begins using it as shown in the following pseudo code:

Producer loop

While not done recording

While current block is not empty, do nothing
End while not empty
Fill the current block
Switch to other block

End while not done recording

End producer loop

The process that writes a full block to disk, uses the opposite value of the empty field to know when a block is ready to write. Its spin loop is as follows:

Consumer loop

While process active

While current block is empty, do nothing
End while empty
write full block
switch to other block

End while process active

End consumer loop

This two-threaded parallel consumer-producer process forms the basis of the DIS VCR storage and retrieval scheme.

The version identifier shown in Figure 4.1 will allow future DIS VCR versions to select replay algorithms based on its number. The total number of PDUs stored in a block is entered in the count field and is used to delimit the block play loop. The offset array values point to PDU

locations in the data array. The offsets were required for storing and accessing variable length PDUs. Offsets are calculated as follows:

$$\text{current offset} + \text{PDU length}$$

Finally, the data array is a large character array for storing PDUs back-to-back. Getting PDUs in and out of the array is analogous to reading and writing one PDU at a time, but it is read into memory as a block and parsed using the PDU count and offsets.

4.4.3. Filtering the Input. In section 3.4.4 we stated that the DIS VCR design was built to accommodate certain filtering of input PDUs. The programming methods chosen to isolate a specific exercise, site, host, entity ID, range of entity IDs, and capturing of certain PDU types, are shown in Table 4.3. Since the exercise ID and PDU types are likely to be used the most, they are included in the interface component for recordings.

Table 4.3. DIS VCR Filters

FLAG	SET BY
Site ID	Command line switch
Host ID	Command line switch
Entity ID	Command line switch
Entity ID Range	Command line switch
Exercise ID	Command line switch or Interface
PDUs to Capture	Command line switch or Interface

4.4.4. Limiting the Overhead. We wanted the record loop to be as efficient as possible, but still have it provide feedback to the user on its progress. Progress updates require expensive screen I/O and could cause the loss of PDUs when entity counts are high. The solution to this problem is to limit the number of updates. Our record loop implementation uses a modulus function to limit

those updates to every 50th PDU. However, the user will look for progress immediately, therefore progress is also updated on the first PDU.

4.4.5. Record Loop. The record function that takes PDUs from the network and stores them to disk is shown below in pseudo code.

Pre-processing Steps

*Spawn the two-thread producer-consumer process
Get information for the file header from command line switches and the interface
Resolve any input errors
Start the simulation clock with local time at standard speed*

Recording Loop

*While not done
 If no PDU in five seconds, show message
 Get a buffered PDU from the daemon
 If PDU fits all parameters
 Copy it to the PDU block structure
 If first PDU, set file start time
 End If
 Store the receipt time with the PDU and write a value to the pointer array
 Update the displayed clock with simulation time
 Mark the daemon buffer empty
 If the block's count = MaxCount or block is full, mark it full and swap blocks
 (the consumer detects the full condition, writes the block to disk, then marks it empty)
 If PDU count is one or on a fifty boundary, show progress update to user
End While*

End Record Loop

*If the user stopped before a MaxCount or full count, mark last block full
Set file stop time to time of last PDU received
(the consumer detects the full condition and writes the last block to disk)
When write is complete, write header, close file, and set it up for immediate replay
Kill the consumer process, it is no longer needed*

End Record

Note that the code allows for feedback to the user, but not on every PDU. This overhead saving strategy puts 49 *if* statement executions in place of 49 graphics screen updates.

4.5. Playback

4.5.1. Reading and Using Header Information. The file header shown in Table 4.2, is read when a file is first selected (see Appendix A on how to select a file). The DIS VCR uses the simdate and start_time header fields to set the simulation clock's initial time and date. They are also used with the rest of the data to populate the identifying information on the right side of the main VCR screen shown in Figure 4.2.

4.5.2. Replay With a Simulation Clock. The simulation clock is used to control replay functions by means of scaling. When the scale of the simulation clock changes, that change must be communicated to all modified applications using the DIS VCR for replays to prevent the problems discussed in section 3.2.3.1. The following sections discuss the mechanism for communicating scale changes and how a change in scale affects each replay function.

4.5.2.1. A New PDU for DIS Replays. The Replay PDU supports the following actions:

- Switch mode to PLAY, PAUSE, or STOP
- Update the simulation clock time or date
- Change the time scale
- Initialize, start, or stop the replay

Whenever the DIS VCR changes mode, time or speed, it transmits a Replay PDU on the network to report the change to receiving applications. The functional actions are captured in the replay state diagram of Figure 4.3 and are discussed in subsequent sections.

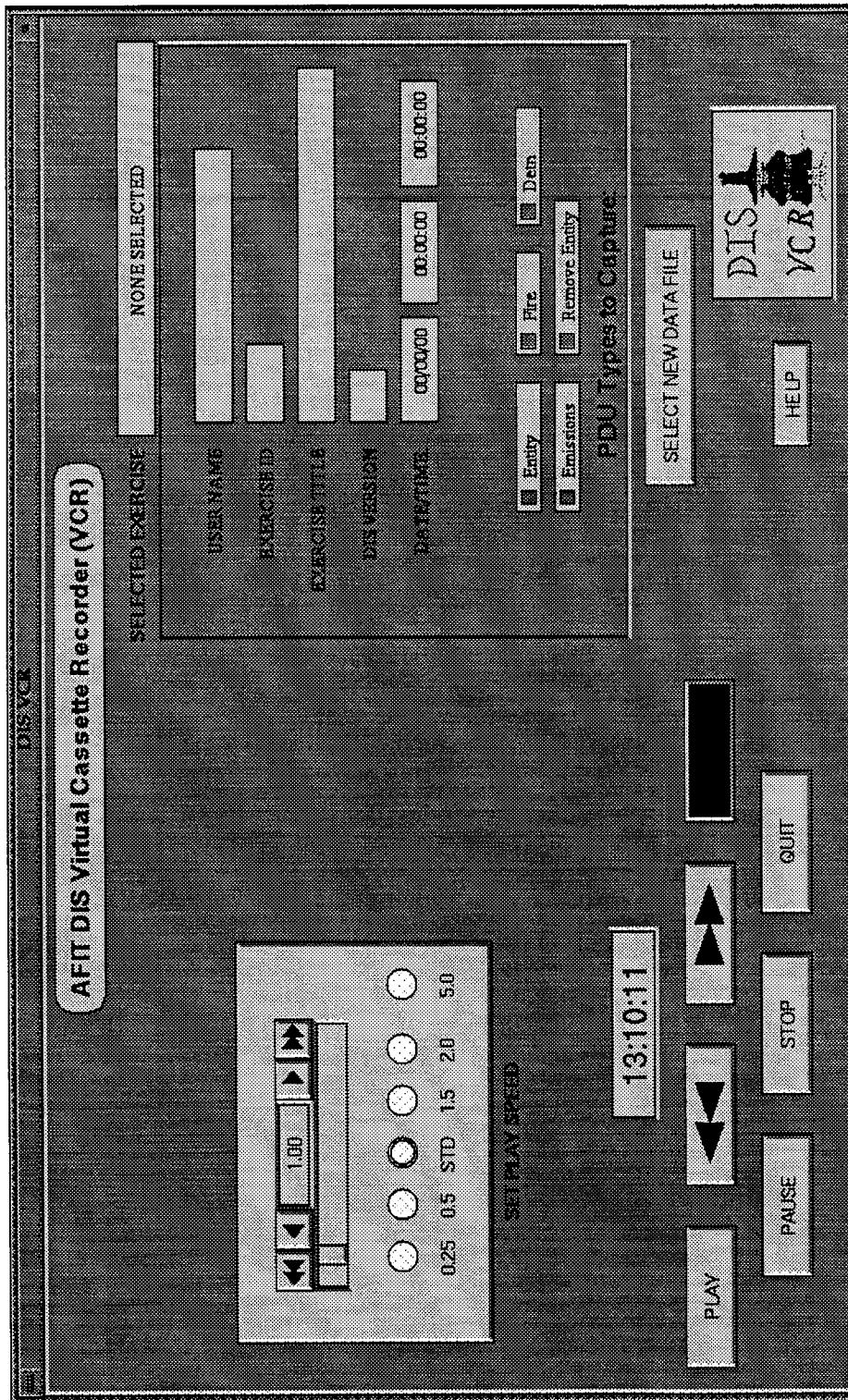


Figure 4.2. Main VCR Screen

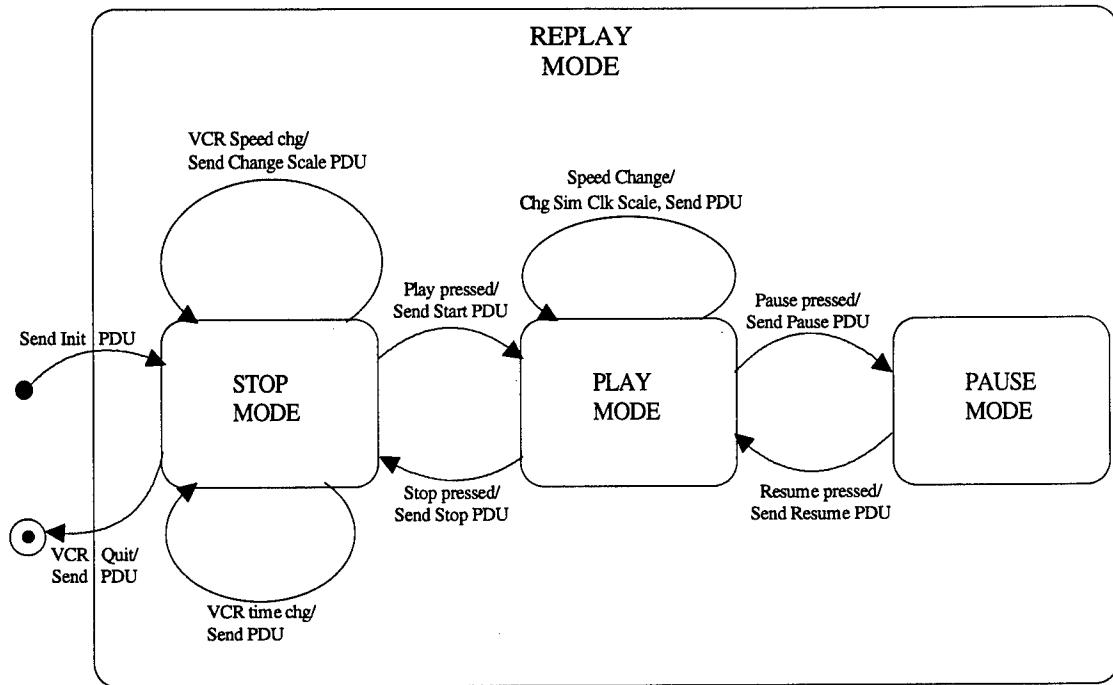


Figure 4.3. Replay State Diagram

As depicted, replay initialization is what signals the application to start using its simulation clock instead of the system clock. The terminal condition (a circle with a dot in it) causes the application to revert back to using the system clock. Each state transition generates a Replay PDU formatted as shown in Figure 4.4. The shaded area is the common PDU header described in section 2.2.1. The final seven fields are used to represent replay actions and variables.

The Replay PDU is patterned after other DIS standard PDUs to maintain compatibility with them and for submission as an addition to that standard. For example, the simulation time field is identical to the simulation management PDU time stamp (2:102) and the enumerations all begin with other as specified in (12).

The Request ID contains a value of zero on the broadcast of the initialization Replay PDU. Every broadcast of a Replay PDU increments the value of the Request ID. When the value of

Request ID reaches 256, the value is reset to one. These values let the receiving application sequence the incoming Replay PDUs.

Size-bits		Replay PDU Fields
96	<i>PDU Header</i>	Protocol Version - 8 bit enumeration
		Exercise ID - 8 bit unsigned integer
		PDU Type - 8 bit enumeration
		Protocol Family - 8 bit enumeration
		Time Stamp - 32 bit unsigned integer
		Length - 16 bit unsigned integer
		Padding - 16 bits unused
48	<i>Originating Entity ID</i>	Site - 16 bit unsigned integer
		Application - 16 bit unsigned integer
		Host - 16 bit unsigned integer
48	<i>Receiving Entity ID</i>	Site - 16 bit unsigned integer
		Application - 16 bit unsigned integer
		Host - 16 bit unsigned integer
64	<i>Simulation Time</i>	Hour - 32 bit integer
		Time Past Hour - 32 bit unsigned integer
32	<i>Time Scale</i>	32 bit float - 0.1 to 10.0 for the VCR
8	<i>Request ID</i>	8 bit integer
8	<i>Mode</i>	8 bit enumeration (12) - 0 Other - 1 Stop - 2 Pause - 3 Play
8	<i>Direction</i>	8 bit enumeration (12) - 0 Other - 1 Forward - 2 Reverse
8	<i>Reason</i>	8 bit enumeration (12) - 0 Other - 1 Initialize - 2 Start - 3 Pause - 4 Resume - 5 Stop - 6 Quit - 7 Change Time - 8 Change Time Scale - 9 Change Direction

Figure 4.4. 320-bit Replay PDU

4.5.2.2. The Speed Change Process. When the user selects a new speed, the DIS VCR sends out a Replay PDU to change the time scale. The simulation time, time scale, and reason are all updated to reflect the new state and the request ID is incremented. The VCR displays the new speed, sets its simulation clock speed to the new value, and begins releasing PDUs accordingly. Upon receiving the Replay PDU, the receiving application's dead-reckoning and entity time-out algorithms use the new scale to control their activities.

4.5.2.3. Speed Limits. The DIS VCR's slowest and fastest replay speeds are one tenth and ten times that of standard wall clock time. Although speeds outside this range are possible, we chose the same values typically used in home VCRs. Realistically, the maximum speed is a limit imposed by the speed of the replay loop which is governed in part by the network interface and the hardware.

4.5.2.4. Pause. When pause mode is selected, a Reply PDU is prepared with the current simulation time with mode and reason set to pause. The DIS VCR sets the simulation clock scale to zero which freezes the PDU stream at the current point in the PDU block. The receiving application is responsible for keeping entities in its current player list alive until a resume Replay PDU is received.

4.5.2.5. Applications and Replays. The synchronization problem discussed in section 3.5.2.4 does not have a perfect solution in the absence of a shared real-time clock. One compromise is to have the DIS VCR send the time-scale Replay PDU to the receiving application and wait for some set amount of time (e.g. one second) before changing the scale on its simulation clock. The amount of time to wait is dependent on the network's efficiency, routing, and current load and therefore makes this a non-viable solution. A second way to handle DIS VCR and

receiving application synchronization, is to add a field to the Replay PDU for the local time when the change becomes effective. Neither program would change the simulation clock until the local time matched the time specified for the change. This solution only works if the local clock times are within milliseconds or less of each other. Thus, the sending and receiving sites would need some way of ensuring the clocks match. Finally, the synchronization could be ignored if the user does not mind a little settling time after speed changes. This is what the DIS VCR does since any other solution would be out of the scope of this thesis effort.

4.5.3. Replay Overhead. An overhead reducing strategy similar to the one in the record loop is also used in replays for progress feedback. However, the same efficiency could not be achieved because the play loop performs repeated clock comparisons on every PDU to time their release. The play loop also checks for speed and pause changes during a replay; something record does not need to do (see section 4.5.4). These differences create more branch conditions to test which slows down the play loop. See Chapter V for data on replay maximum speed versus entity counts.

4.5.4. Play Loop Pseudo Code. The play function that takes PDUs from the disk and re-transmits them across the network, is shown below in pseudo code. The user may change speeds, pause, and stop while inside play's PDU block loop.

Pre-processing Steps

Select a file if one is not loaded

Read the header, set the simulation clock, and populate info on VCR main screen

Hold the simulation clock until the loop begins

Spawn the two-thread producer-consumer process that gets data from disk

Read first two blocks

Start the DIS VCR simulation clock

Fill and send an initialization Replay PDU

End Pre-processing Steps

Outer loop

*While Not stopping and Not end-of-file
Hold for full PDU block*

PDU Block Loop

While Not stopping and Not end-of-block or end-of-file

Capture user inputs

If in PLAY mode

Check for speed changes, set if changed by user

Get daemon buffer and copy current PDU to it

While PDU time Not equal to simulation clock time

Check user input, respond to STOP, PAUSE, and speed changes

STOP: Set stop variable to drop out of loops

PAUSE: Stop clock, set mode=PAUSE

SPEED: Change clock scale and continue this loop

End While PDU time Not equal to simulation clock time

Mark the daemon buffer full so it will send it

Update displayed clock and progress indicators

End if PLAY mode

Else PAUSED

If resume then

Set mode=PLAY

Send mode-change Replay PDU

Restart simulation clock

End if resume

End Else PAUSED

End While Not stopping and Not end-of-block or end-of-file

End PDU Block Loop

Swap to next PDU block

End While Not stopping and Not end-of-file

End Outer loop**Post-processing Steps**

Kill the producer process, it is no longer needed

Send STOP mode Replay PDU

If end-of-file (eof)

Reset data file to the beginning

End if eof

Else

Reset data file to beginning of current block

End else

End Post-processing steps

4.6. The DIS VCR Interface Implementation

The main theme for the DIS VCR interface design was a simple emulation of the home VCR with goals to:

- Reduce the interface learning curve
- Maximize task speed
- Minimize the user error rate
- Supply easy access to help
- Provide easy recording or data file identification

Since our primary user is the same as RDT's, we satisfy the first goal by leveraging our user's familiarity with RDT's interface by reusing the same high-level interface tools as in RDT. This makes the Forms Library (16) the tool of choice for building the DIS VCR interface. The Forms Library was built to reduce the time consuming process of constructing the user interface on Silicon Graphics Workstations. The main theme of an interface built with the Forms Toolkit, is a form (a window-like object) that is populated with interaction objects that signal events or issue direct call-backs to user defined functions. The interaction objects include all those identified in section 3.6.3.1.1 and several others. Each of the following sections shows the form that was created for each screen shown in Figure 3.3 and discusses its actions and contribution to satisfying the interface goals.

4.6.1. The Main VCR Form. The main DIS VCR form gives a user access to all of the DIS VCR's functionality (see Figure 4.5). From here, users can initiate a replay, recording, or actions to direct the current replay. The main form is divided into four functional groups which are geographically separated. In the upper left corner of the form, there is a cluster of three objects used to control the replay speed. On top is a counter object with two increment buttons on each side. The outside buttons change the speed by ± 0.1 and the inside buttons modify it in

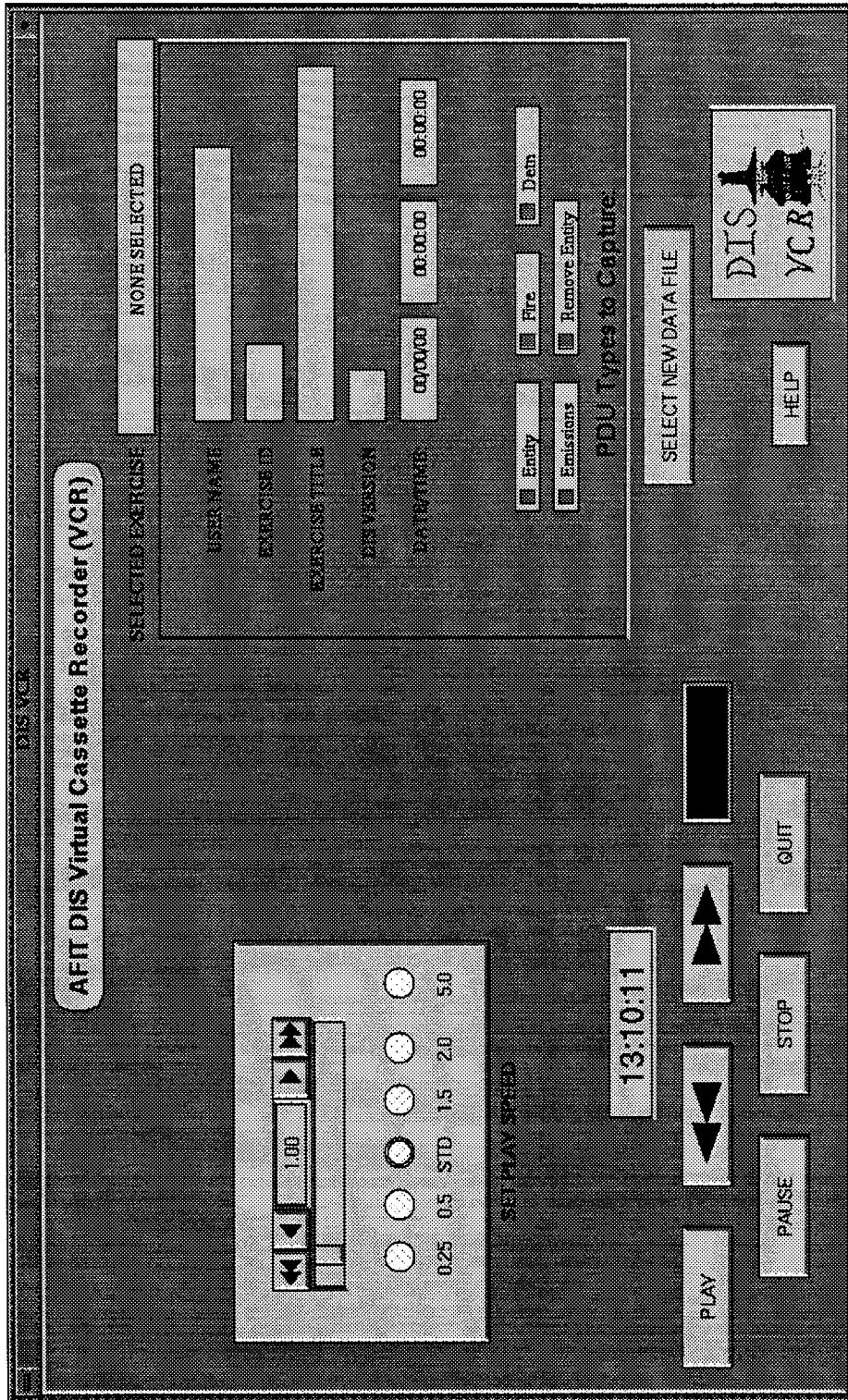


Figure 4.5. Main VCR Screen

± 0.01 increments. The center object slides from 0.1 to 10.0 in steps of 0.01 and returns its value when released. Positioned below the slider, there is a group of radio buttons allowing the user to select one of six typical speeds. This final object helps satisfy the goal of minimizing task speed since a single mouse click will change the replay speed. Also, since the user never enters a speed value directly, an error cannot be made.

The button controls emulating the typical VCR are clustered below the speed group. The meaning of the labels are identical in scope and function to a Video Cassette Recorder which helps to reduce the learning curve even further. Just above these buttons is the simulation clock display with time shown as military time.

The identifying information about the current recording is grouped together in the middle-right side of the form. Nothing is selectable in this group, it is an "information only" copy of pertinent file header information from Table 4.2. This information group contributes to meeting the easy identification goal. Furthermore, the information reminds the user of which PDUs are included in the recording, the duration of the replay, and when it will stop.

Finally, one of the two buttons on the lower right provide access to the on-line help while the other lets the user start a new file selection process (see section 4.6.3).

Once a recording has started, a lack of incoming PDUs for five seconds triggers the message shown in Figure 4.6. This lets the user know that either the simulation has not begun, the daemons were not started properly, or that something is wrong with the way the record filters were specified.

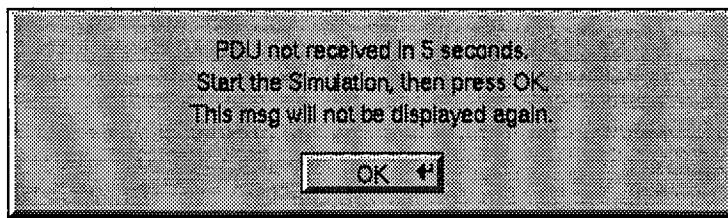


Figure 4.6. Time-out Message for PDUs

4.6.2. Record Form. The record information is entered using the form shown in Figure 4.7.

The input fields on the left simplify data entry and reduce the user's error rate by restricting the type of information a user may enter (characters or numbers). The buttons on the right allow the user to select which PDUs to capture. These buttons light up when the PDU is selected for capture (user feedback). Pressing the done button starts the record process, or the user may select the cancel button to gracefully exit the record form and return to the previous state. In addition, there is a button for help on the record form.

The DIS VCR looks for certain errors after the done button is selected. First, it ensures that the file name field was not left blank. If it was, the user is informed with the message shown in Figure 4.8 and is returned to the record information form when OK is pressed. Next, the DIS VCR

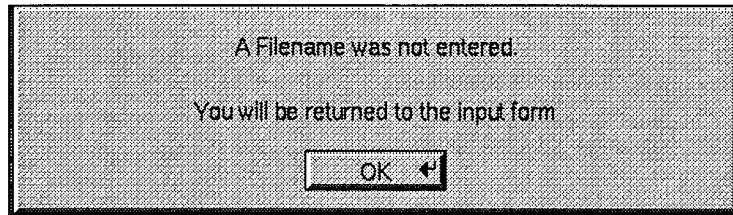


Figure 4.8. File Name not Entered Message

checks to see if a duplicate file name already exists in the directory. If the file name has previously been used, the user is asked for overwrite confirmation using the form in Figure 4.9. A

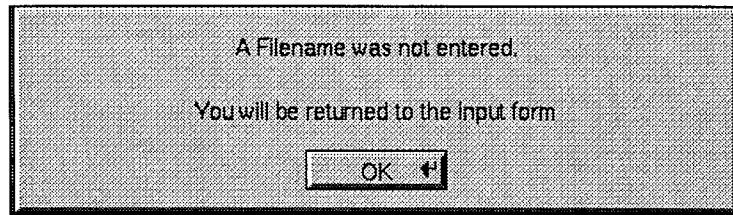


Figure 4.9. File Name Exists Message

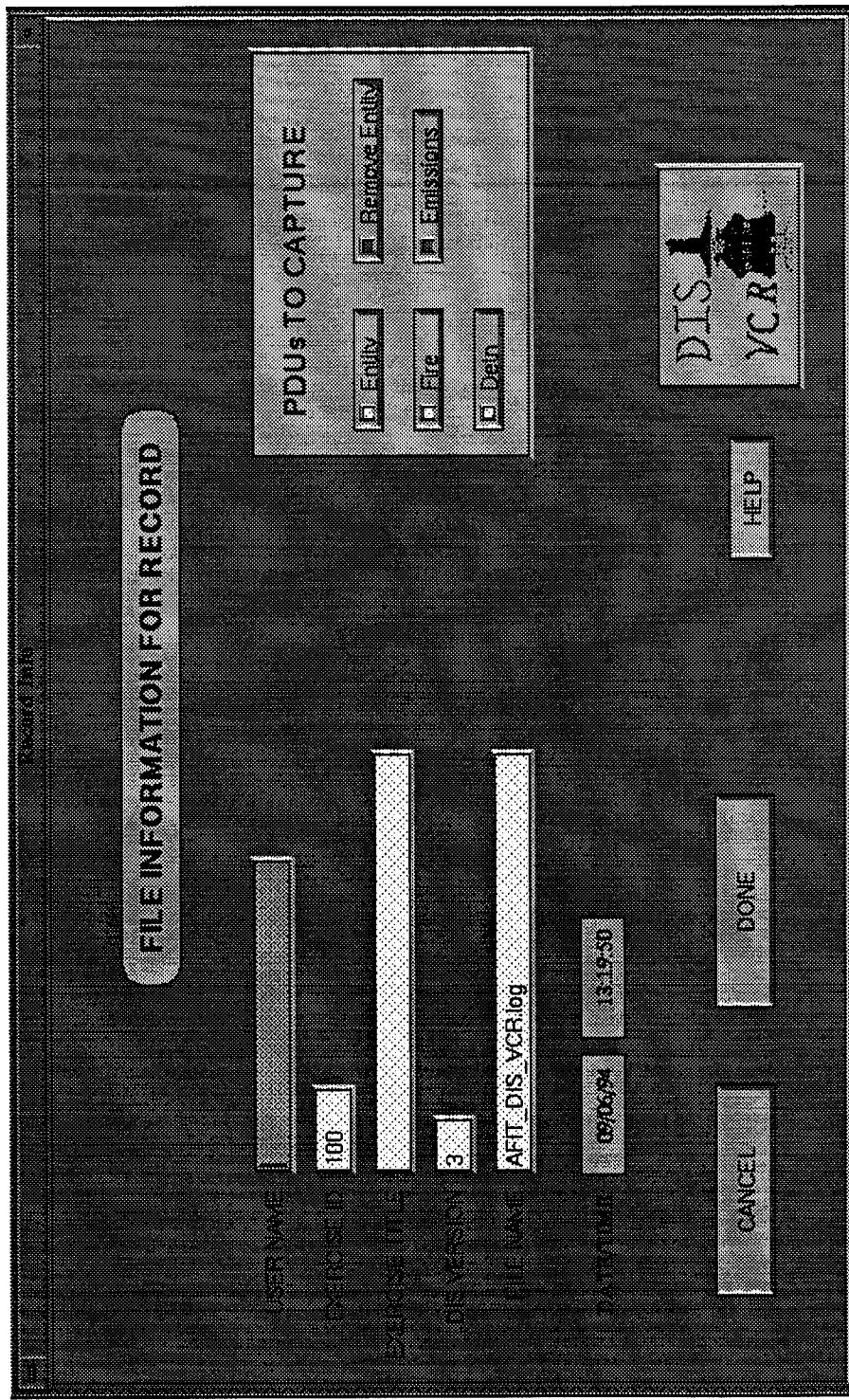


Figure 4.7. Record Form

yes answer overwrites the existing file with the new recording; otherwise, a no answer returns the user to the record form to allow modification to the file name.

When all the errors have been cleared, recording begins and the progress form in Figure 4.10 is displayed. The form uses a red bar to indicate progress; it also displays an accumulated count of received PDUs. These indicators provide nominal feedback to keep the user aware of the recording's progress.

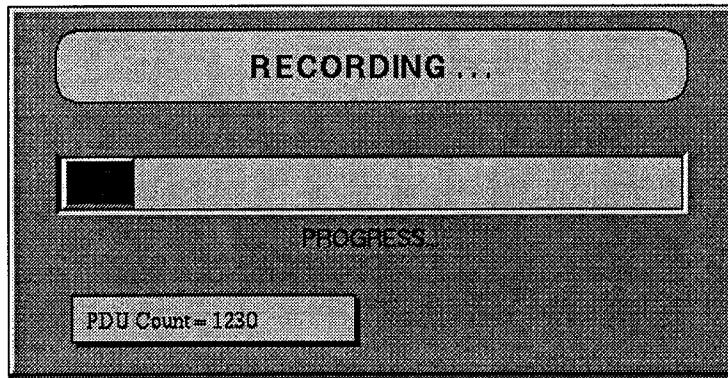


Figure 4.10. Progress Form

4.6.3. Select Exercise Form. The selection form gives users an easy convenient way to select and load data files for replay. The key selection object is the pick-list on the left side of the form as shown in Figure 4.11. When the user picks a file from the list, its identifying information is displayed in the object group on the right. After selecting a file, the user can delete it or load it for replay using the corresponding buttons. Like the record and main DIS VCR forms, this screen has direct access to on-line help. The cancel button lets the user gracefully exit the selection form and return to the previous state.

If the selected file is not a DIS VCR recording, the user is informed with the form shown in Figure 4.12 and returns to the selection form. If the user selects the load button prior to choosing a valid file, the message in Figure 4.13 is displayed after the file selection form is closed.

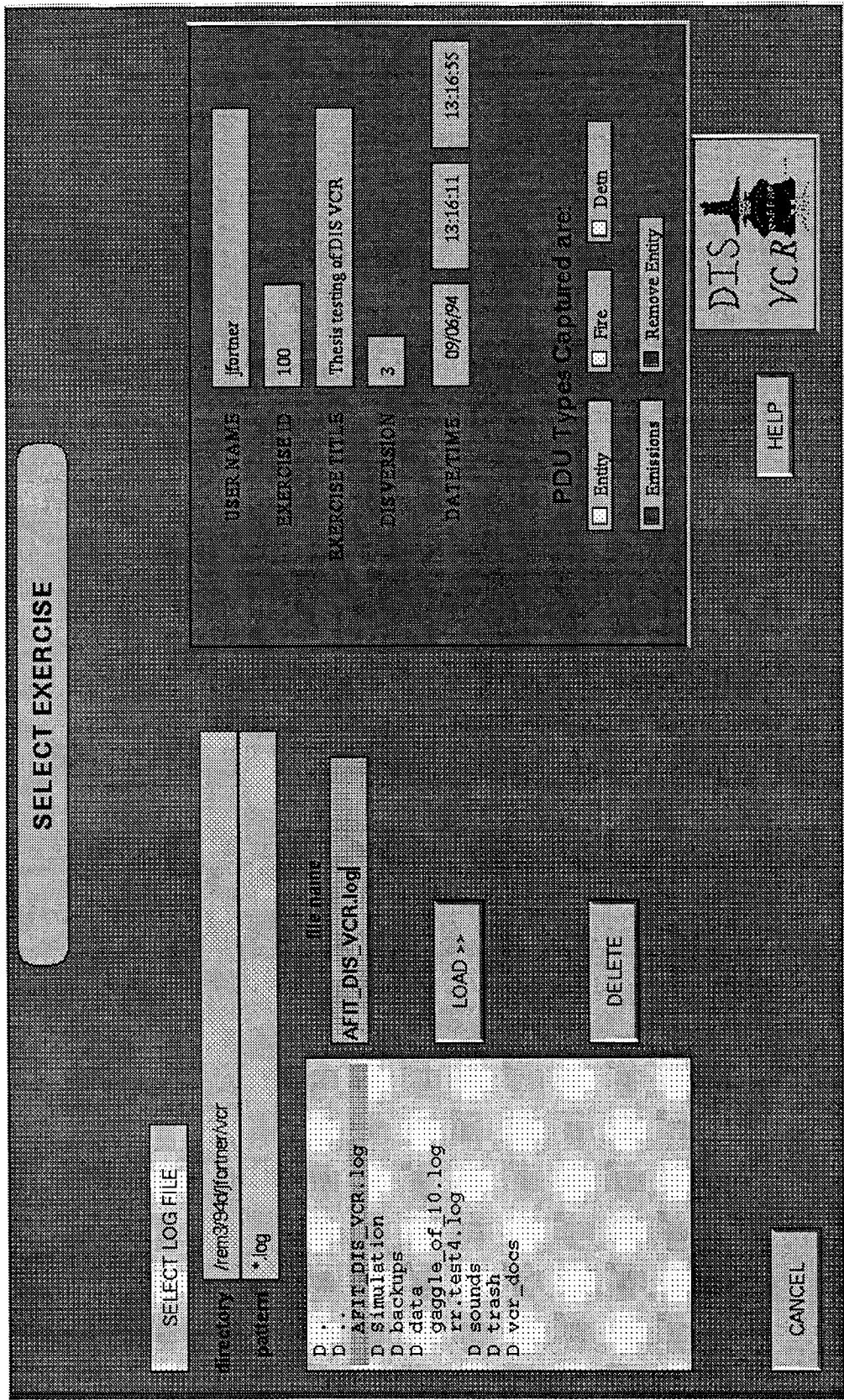


Figure 4.11. Select Exercise Form

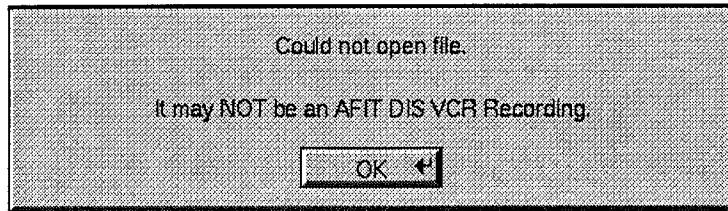


Figure 4.12. File is not a DIS VCR Recording Message

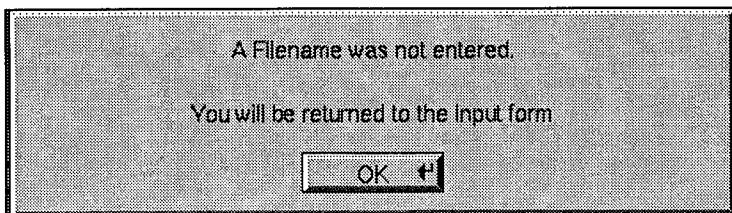


Figure 4.13. File was not Selected Message

These messages let the user know when something has gone wrong and needs to be corrected.

They also play an important role in satisfying our interface goal of reducing user errors.

Once a file is successfully loaded, play begins and a progress form similar to the one for record is displayed. The only difference is that the progress bar is blue and the title reads play progress (see Figure 4.10).

4.7. Implementation Summary

In this chapter we presented our DIS VCR implementation which included a simulation clock with scalable time and a Replay PDU that communicates time and speed changes to applications. The clock and Replay PDU events were incorporated in the record and play loops and illustrated using detailed pseudo code of those processes. To complete the building of the DIS VCR, a Forms-style interface was added that met the goals set forth in Chapter III. The design and implementation phases included some concurrent and post testing of DIS VCR performance. The test results are found in Chapter V which discusses replay speed limits, disk utilization, and network statistics.

V. Performance

5.1. Introduction

Throughout design and implementation, various aspects of the DIS VCR were analyzed and tested. Early experiments with record and playback affected the selection of the storage and retrieval scheme and indicted areas for subsequent testing. The DIS VCR's performance is directly linked to disk I/O and network performance prompting extended investigations of these areas. This chapter presents DIS VCR performance data gathered in testing and analyzes some anomalies that occur in replays.

5.2. Network Performance

Part of the early experiments with the play loop clearly demonstrated the limits of the standard AFIT network daemons. The play loop was set up with minimal overhead so that it could send PDUs out at maximum speed. Even the most efficient loop, which did not depend on disk I/O, could only send 900-1100 PDUs per second. This prompted the insertion of time calls before and after the daemon interface routines to measure their speed. The time measurements identified the daemons as a bottle-neck. The author of the daemon code, Bruce Clay, said that it was not uncommon to only get 350 PDUs per second per processor and cited 1500 PDUs per second as the maximum attainable performance using a four processor ONYX.

Replays can lose PDUs due to the relaxed UDP/IP protocols employed by DIS. This effect would be cumulative when using the DIS VCR as a demonstration building tool. This prompted us to check the robustness of the UDP/IP protocol on our local network. The test used the DIS VCR to transmit a predetermined number of PDUs onto the network and a PDU monitor who's only task was to count the number of PDUs received. Of the 45,000 PDUs sent in each run, two PDUs were

lost. This means that 0.00044% of PDUs transmitted may not make it to local receiving applications. As the error accumulates, it could cause DIS players to momentarily drop out of the simulation and be reloaded on the next update.

5.3. Storage and Retrieval Performance

We also inserted code to measure disk I/O performance for the single and block PDU storage and retrieval schemes. This test demonstrated that the block approach could handle almost 10 times as many PDUs as the single PDU method. Hard disk transfer rates varied from 0.55-3.6MB per second when reading or writing one PDU at a time and from 2.68-22.34MB per second for blocks of 1000 PDUs. The average transfer rate for a 1000 PDU block was 13.1MB per second which supports 85962 PDUs per second. Unfortunately, the daemons can only handle a fraction of that and, even if they could handle it all, the Ethernet bandwidth could not. According to the system administrator, the local Ethernet has a bandwidth of 1.25MB per second with only about half of that available for user applications. If no other applications are using the network, the Ethernet can only handle about 3125 PDUs per second with an average packet size of 200 bytes (18:394). Therefore, it is safe to predict that the DIS VCR PDU block I/O performance will not require improvement for some time and will not be fully utilized until substantial enhancements to the network and daemons occur.

The DIS VCR can store 6562 entity state PDUs per megabyte using the block storage and retrieval scheme of section 4.4.2. The combination of *readred* and the DIS VCR lowers the storage requirement for remote debriefings by 4.4 to 17.5 times over the method depicted in Figure 2.5. Data storage comparisons are shown in Figure 5.1. The dead reckoning threshold *readred* uses (1 or 10 meters), affects the actual storage space needed for a DIS VCR recording as shown in the figure.

DATA STORAGE MODE	STORAGE	LENGTH	1m Dead-Reckoned <i>readred</i> PDU Output	10m Dead-Reckoned <i>readred</i> PDU Output
RAW DATA	184 MB	44.65 mins	184,078 PDUs	46,596 PDUs
XFILTERED	123 MB	44.65 mins		
DIS VCR	7-28 MB	44.65 mins		
RAW DATA	21.40 MB	5.18 mins	Unknown	8,036 PDUs
XFILTERED	12.66 MB	5.18 mins		
DIS VCR	1.37 MB	5.18 mins		

Figure 5.1. DIS VCR and *readred* Storage Comparison (1:133)

5.3. PDU Rates and Replay Speeds

Since the daemons can only process 900-1100 PDUs per second, the maximum speed of the replay loop is limited by the entity count, or more precisely, the average number of PDUs received per second. Table 5.1 lists average PDU counts and shows the maximum replay speed for each.

Table 5.1. Average PDUs Per Second and Replay Speeds

Low PDUs/sec	Avg. PDUs/sec	High PDUs/sec	DIS VCR Speed
312	380	698	1.3
281	351	465	1.5
262	290	440	3.3
141	160	213	5.8
127	129	243	6.7
60	80	100	8.6
31	45	92	9.75

Table 5.2 lists PDU rate excerpts from the *10th DIS Workshop: Working Group Minutes* and numbers from a typical *readred* replay. The first two traces were 60 minutes long and consisted of 90-96% entity state PDUs and less than 0.3% fire and detonation PDUs (18:394). The average number of PDUs per second depends on the amount and type of each entity class. For the I/TSEC DIS sample, the DIS VCR could handle 1059 entities at speeds up to 1.3.

Table 5.2. PDU Rates From Other Sources

Source	Avg. PDUs/sec	#Entities
DEC Traces from I/ITSEC scenario week.	62.92	149
	64.92	119
I/ITSEC DIS Sample	75.3	210
readred replay	25	57

5.4. RDT Replay Fidelity

RDT replay fidelity was questioned when testing revealed that 13% of the stored PDUs were not in time stamp order for different entity IDs, even though PDUs for the same entity ID were (caused by the UDP/IP network protocol). We were concerned that RDT's dead reckoning algorithms would move the entity farther than it should have while waiting on the delayed PDU, causing the entity to jump backward on the update. The largest measured delay from the sample was 0.11 seconds. However, discontinuities in entity movement due to out of order PDUs is typically imperceptible. For example, consider an entity moving at 350mph in one of RDT's views.

Given:

Screen size: 1280 X 1024 over a 15.25in square

$$\text{RDT 3D view scale: } 6.00\text{in} = 15\text{NM} ; \frac{6\text{ in}}{15\text{ NM}} = \frac{6\text{ in}}{1094400\text{ in}} = \frac{1}{182400}$$

We can calculate how much the entity will move on screen:

Horizontal pixels per inch:

$$\text{H pixels} = \frac{1280 \text{ pixels}}{15.25 \text{ in}} = 83.93 \text{ pixels/in}$$

Actual distance the entity moved:

$$\text{Actual} = 350 \text{ mi/hr} \cdot 0.11 \text{ seconds} = 677.6 \text{ in}$$

3D View distance moved:

$$\text{3D_move} = \frac{677.6 \text{ in}}{182400} = 0.0037 \text{ in}$$

3D view pixels moved:

$$3D_pixels = 0.0037\text{in} \cdot 83.93\text{pixels/in} = 0.312\text{pixels}$$

Similar calculations for the RDT plan view predict movement of 0.065 pixels in the view's unzoomed state. Obviously the numbers will not hold if we are zoomed on an entity moving at mach 2, but this is not the typical case. Therefore, PDUs stored out of order are of no immediate concern. However, the error could be cumulative if the DIS VCR is used for scenario building. To improve fidelity, the data could be post processed to correct the time ordering problem.

VI. Conclusions and Recommendations

This chapter looks back at the thesis statement and measures success by comparing DIS VCR accomplishments with our original objectives, followed by a discussion of its contributions to the DIS community. The thesis closes with some recommendations for future work that will help enhance this thesis effort, the AFIT DIS environment, and the DIS world in general.

6.1. Thesis Objectives Revisited

The primary objective of the DIS VCR was to add flexible replay capabilities to the Remote Debriefing Tool (RDT). Derived requirements from that objective included the selective filtering of incoming PDUs, variable replay speeds, ability to pause, fast-forward, rewind, efficient data storage and retrieval, and an interface that simplifies the execution of those functions. Secondary goals included a DIS VCR compatible design for concurrent UHF audio replay and an extension to the replay design that supports unmodifiable receiving applications.

To demonstrate the filtering capabilities of the DIS VCR, recordings were made using various combinations of PDU capture switches, exercise IDs, and entity IDs. These were replayed and viewed for correctness using other applications (i.e. RDT).

The various replay functions were put to the test when an RDT-DIS VCR demonstration was created for the Air Force Association Convention in Washington D.C. this year. The demonstration illustrated for the first time, the successful completion of variable speed replay, pause, fast-forward, and rewind. Also, the DIS VCR was used at the convention to replay a Red Flag mission used to demonstrate RDT's capabilities and an AFIT gaggle of 100 entities used to highlight the usefulness of the Synthetic Battle Bridge (SBB). The DIS VCR proved itself while serving literally millions of PDUs to using applications.

Chapter V showed the DIS VCR's storage and retrieval methods to be efficient enough to support the recording and playback of 100,000 entities; ARPA's 1997 goal for entities in a theater-

wide battle simulation of real and "computer generated forces" (4:8). With significant improvements in network and computer performance (about 30-50 times faster), the DIS VCR should be able to record and replay very large scale simulations.

To meet secondary goals, sections 3.7 and 3.8 presented designs for supporting unmodifiable applications and audio replays from signal PDUs. The designs were complete in concept and only need to be implemented.

6.2. Future Work

This section suggests additions to the DIS VCR that will enhance its performance or add to its capabilities and recommends future areas of research and development.

6.2.1. DIS VCR Additions. The synchronization problem between the DIS VCR and replay-modified applications described in section 3.5.2.4 should be corrected using one of the methods described in section 4.5.2.5. The lack of synchronization detracts from the fidelity of DIS VCR replays during speed changes.

The DIS VCR should be modified to allow the user to reverse the replay direction. This would keep the user from having to guess how far to go back to see a particular event again. The Replay PDU is designed to handle the reverse direction, but the DIS VCR and simulation clock would need modified.

Since the DIS VCR includes a way to capture signal PDUs, functions should be added that implement the audio replay design presented in section 3.8. Being able to hear the UHF chatter from Red Flag exercises, would greatly enhance the realism of replays with the RDT-DIS VCR combination. Also, the DIS VCR was implemented to capture a small subset of the 26 possible PDU types. AFIT's projected expansion in this area would require DIS VCR modifications to add any new types we wish to support in replays (e.g. collisions, simulation management, etc.).

The analysis community would benefit from a single-step replay mode that displayed the PDU data and allowed the user to edit and save it. Analysts could use the mode to debug application and network anomalies and test the robustness of an applications tolerance to packet errors as suggested in Chapter 2. This idea could be expanded for use as a scripted demonstration creation tool. Users could plot out an entities adjusted path, edit the data to match, and replay the result. This may also include a way to insert new PDUs into the data stream to correct for network PDU losses or add to fidelity of certain maneuvers. Editing would allow analysts to mark entities as damaged or destroyed when their prediction models indicate a hit or kill.

The DIS VCR has many filters that select specific PDUs for recordings, but only one (exercise ID) that modifies the replay. Replay filtering can be accomplished by re-recording the data, but this ability would be more convenient if it were added to the replay interface.

6.2.2. Other Recommendations. If the DIS community is to meet the goals set by ARPA (4), the network bottleneck must improve. DIS VCR testing demonstrated the limits of the current system and research in its improvement is recommended. AFIT has already taken steps in this direction with research into the design of UDP/IP hardware outboard processing and plans to upgrade the local Ethernet. Research should include improvements to the DIS standard that reduces the amount of bandwidth required for DIS exercises (18).

6.3. Thesis Contribution

The DIS VCR improves and extends the capabilities of RDT by providing one of the two most important functions missing from it, variable-speed replay (1:142). Created as a separate application, the DIS VCR also provides a way to produce Guckenburger's mission training scenarios with measurable performance (see section 2.4.1) and allows any DIS analytical group to use its capabilities. Finally, this thesis effort has proven the effectiveness of a new Replay PDU in orchestrating communications between the DIS VCR and any replay-modified application.

This appendix contains a complete description of how to use the AFIT DIS VCR (from here on the VCR). It covers the details of setting up the equipment, followed by the VCR start-up procedures, then instructions for making a recording and playing it back, and finally a wrap-up section.

A.1. Getting Started

This section explains the hardware and software setup needed prior to starting the VCR. You will also find a list of all applicable files and a description of what each does.

A.1.1. The Hardware. Most Silicon Graphics workstations can run the VCR. However, the VCR can handle more entities on faster CPUs and on multi-processor machines. The minimum recommended computer is a 100MHz Indigo.

The VCR code has a compilation switch for making audio available. An SGI Indigo, with its standard sound card, is sufficient to play the VCR sounds.

The VCR requires a connection to the network. It uses an Ethernet system and a specific set of network daemons written for AFIT (see A.1.2). These must be available for the software to function.

A.1.2. The Software. This section divides the required software list into VCR source code, executable and data files, and network daemon categories. This information is collected into Table A.1 for convenience. The references to directories will assume you are on a machine that has access to the WARBREAKER directories.

Table A.1. VCR Files, Their Functions, and Locations

FILENAME	FUNCTION or USE	LOCATION
EXECUTABLE/DATA		
vcr	Main executable	/usr/people/wb/bin/vcr
*.log	Recorded data files	/usr/people/wb/bin/vcr
vcr.logo.xbm	Bitmap displayed on the main FORM	/usr/people/wb/bin/vcr
SOURCE CODE		
vcr.c	Main source code file	/usr/people/wb/src/vcr
vcr.h	Main include. Defines, VCR types, all externals used in VCR FORMs.	/usr/people/wb/src/vcr
vcr_forms.c	Code that builds all VCR forms	/usr/people/wb/src/vcr
sim_time.h	Types/defines for Simulation Clock	/usr/people/wb/src/vcr
Simulation_clock.cc	Complete source for all Sim Clock functions.	/usr/people/wb/src/vcr
Simulation_clock.h	Specification header for .cc	/usr/people/wb/src/vcr
NETWORK		
sgi_recv	Executable for the receive daemon	/rem4/afa94/bin
sgi_sendd	Executable for the send daemon	/rem4/afa94/bin

In addition, the workstation must have access to G/L libraries and standard system calls; however, these are included in the latest release of IRIX. The listed source code is not needed for execution, it is only included for completeness.

A.1.3. Before Starting the VCR. The way you set up your machine before starting the VCR depends on how you intend to use it. First, determine the daemon setup using the following command line

```
ps -elf | grep sgi
```

This will locate any active daemons and show you most or all of the command line invocation. The *-p* and *-b* switches are the most important because they tell you which port you will send or receive on (usually 3000) and how many buffers (typically 100) each daemon is using, respectively. Also of interest is the *-o* switch. Typically, DIS applications both send and receive, so the daemons are

set up to prevent reception of PDUs sent on the same host. The *-o* switch overrides this default setting so you can run an application that sends only and one that receives only, on the same machine. In these cases, the VCR is used to send replayed PDUs or to receive and record them. Be cautious here, you DO NOT want two applications running on the same machine if they will compete for daemon buffers. For example, if both programs are actively receiving PDUs, one will get some and the other will get the rest. This results in applications losing PDUs and causing entities to randomly drop out of the simulation.

If the *ps* command does not show the *-o* switch, the correct port, or enough buffers, use the following commands to stop the daemons

```
/rem4/afa94/bin/sgi_recv -p##### -q  
/rem4/afa94/bin/sgi_send -p##### -q
```

where ##### is the port number shown by the *ps -elf | grep* call. Now restart the daemons with the settings you need. If you use the *-o* switch, be sure to list it before the others as shown in the following examples.

```
/rem4/afa94/bin/sgi_recv -o -p3000 -b100 &  
/rem4/afa94/bin/sgi_send -p3000 -b100 &
```

The & means to run this process in the background and will return you to the prompt after the daemons are setup.

IMPORTANT: When using different hosts in simulations, you must have all the hosts' daemons on the same port or the simulations will not communicate with each other.

A.2. Starting the VCR

Some applications need to receive an initialization replay PDU before they will switch to their simulation replay clock. So, be sure to start the VCR after the receiving program is loaded. This is only necessary if you intend to use speeds other than standard.

When starting the VCR, you may want to include some of the command line switches it supports. Table A.2 lists all the switches and their effect on recording and playback. For record, the switches specify the filters that limit which PDUs the VCR will capture and set the initial default values for the record form. The site, host and entity IDs are set only by the command line switches. If a particular filtering switch is not used, the VCR will assume you wish to capture all PDUs regardless of its ID. For example, if the VCR is started as follows

```
vcr -e2
```

you would be preparing to record entities from any site or host with an entity ID of 2. If you use *-e*, *-l*, and *-u* together, only the *-e* will be recognized and just the specified entity ID will get recorded, not a range.

Table A.2. VCR Command Line Switches and Effects

SWITCH	RECORDING	PLAYBACK
<i>-i</i>	Set Default Exercise ID to record	Set Exercise ID for Replay
<i>-s</i>	PDU Site ID to record	No affect
<i>-h</i>	PDU Host ID to record	No affect
<i>-e</i>	Single Entity ID to record	Not Implemented
<i>-l</i>	Range starting Entity ID to record	Not Implemented
<i>-u</i>	Range ending Entity ID to record	Not Implemented
<i>-L</i>	No affect	Repeat Replay of Same File
<i>-E</i>	Set Default Flag to Capture Entity State PDUs	No affect
<i>-F</i>	Set Default Flag to Capture Fire PDUs	No affect
<i>-D</i>	Set Default Flag to Capture Detonation PDUs	No affect
<i>-M</i>	Set Default Flag to Capture Emissions PDUs	No affect
<i>-R</i>	Set Default Flag to Capture Remove Entity PDUs	No affect

A.3. Making a Recording

Now that you are familiar with command line switches, we can look at the record process.

After starting the VCR with any switches you wanted, you will see the main VCR form shown in Figure A.1. The Selected Exercise information will be blank, the VCR's clock is set to the local time, and the speed controls are all set to the standard speed of 1.0.

To begin a recording, simply press the RECORD button. This will bring up the record input form shown in Figure A.2. Table A.3 shows each input field on the form, whether it is an optional or mandatory entry, the type of data to enter, and any error checking on the field. All input fields respond to the commands shown in Table A.4. The input fields will have default data in them or the data entered from a previous recording. To readily identify a recording, you should enter your user ID and a title describing the simulation. Also, you must enter an exercise ID and a file name. The VCR will append a ".log" to the end of the file name you enter, to make it readily identifiable.

Table A.3. Record Form Input Field Parameters

INPUT FIELD	REQUIREMENT	DATA	ERROR CHECKS
USER NAME	Optional	String of any characters	None
EXERCISE ID	Mandatory	Integer	Only accepts integers.
EXERCISE TITLE	Optional	String of any characters	None
DIS VERSION	Not modifiable	String of any characters	None
FILE NAME	Mandatory	String of any characters	Error if left blank. VCR checks for duplicate file names.

Table A.4. Input Field Key Reference

KEY USED	RESPONSE
TAB	Move to the next field
ESC	Clear the field
ENTER	Accept data and move to the next field
END	Move cursor to the end of any text
INSERT	Toggle insert/type-over mode
HOME	Move to the start of current field

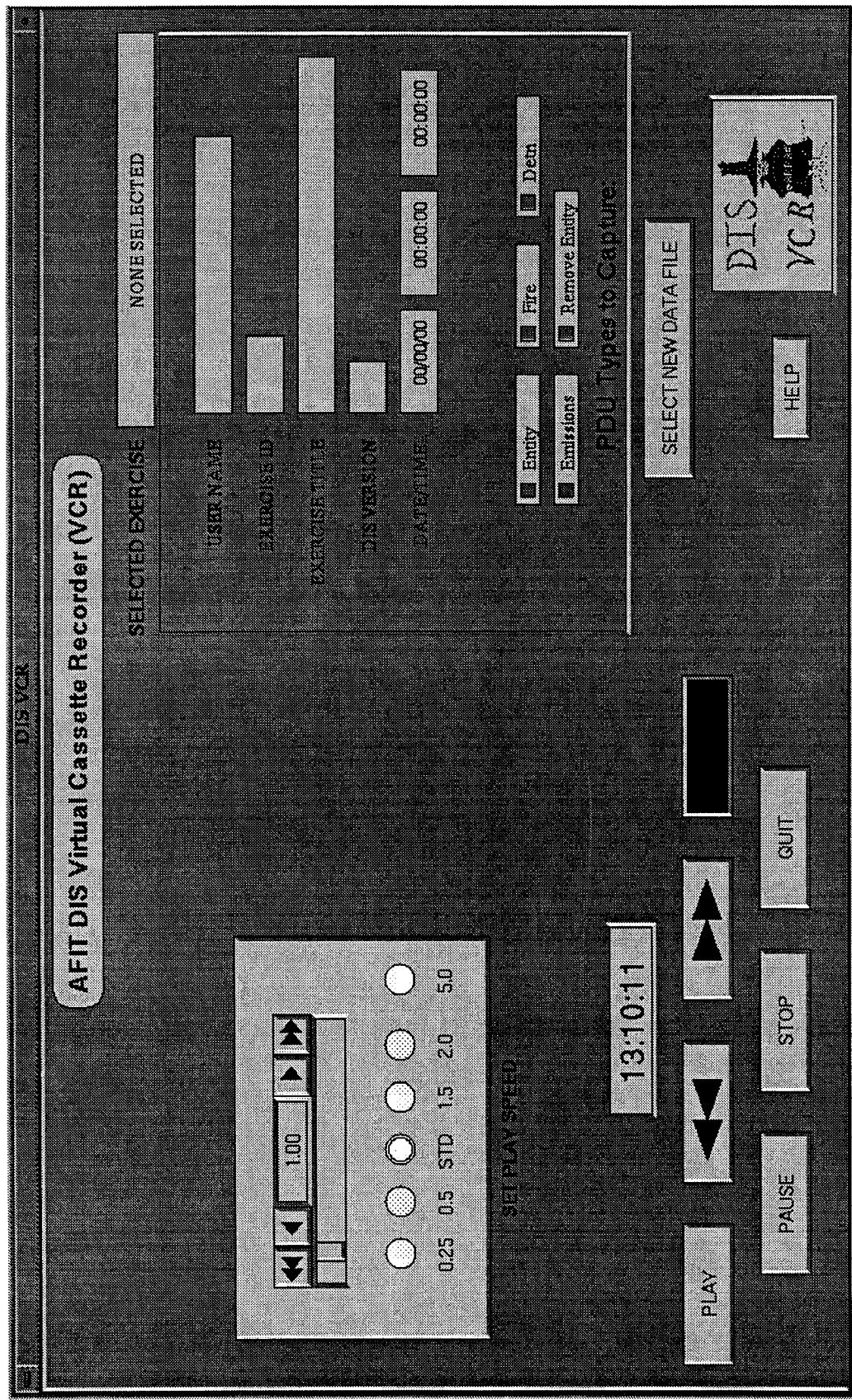


Figure A.1. Main VCR Form

Record File

FILE INFORMATION FOR RECORD

FILE NAME	DIS VCRlog
EXERCISE ID	100
EXERCISE TIME	13:19:50
DEV VERSION	3
FILE NAME	DIS VCRlog
SATellite	890694

Entity Remove Entity
 Site Emissions
 Den

DIS VCR

HELP

CANCEL DONE

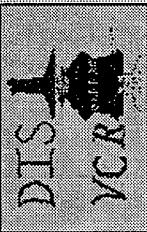


Figure A.2. Record Input Form

For initial recordings, the "PDUs TO CAPTURE" buttons will have the Entity, Fire, and Detn (Detonation) lit up. Use the mouse to select additional PDU types or to deselect those you do not want to capture. At least one PDU type should be selected, or the VCR will record nothing.

The VCR sets the site, host, and entity IDs to zero (meaning all) and the exercise ID to 100, unless you used the command line switches to change them. The record form does allow changes to the exercise ID but will initially display the one set by the command line or the default of 100. Set this value to the one agreed to by all simulation participants. To capture PDUs from any exercise ID, set it to zero.

To start recording, press the DONE button. The VCR will check for errors and inform you of any before proceeding. For example, if the file name already exists, it asks if you want to overwrite it. A no answer will return you to the form to change it. Once errors are resolved, the VCR closes the record information form and copies the new information to the main VCR form and PDU processing begins. The progress form, shown in Figure A.3, has a red progress bar and shows a PDU count. The progress bar and the VCR clock are updated on every 100th PDU and the count on every 10th. However, they all update on the first PDU so you know immediately if the VCR is receiving PDUs that match your parameters. If the record loop does not receive any matching PDUs in the first five seconds, a message dialog will warn you. Once you press the OK button, the loop will wait until a PDU comes in or STOP is selected.

To determine how long you have been recording, compare the start time shown in the information box to that of the VCR's clock. This is important because the VCR does not check for available space before trying to write data to disk. Check the available space before recording and monitor it periodically when disk space is limited. Table A.5 shows time versus disk space requirements for various entity counts to help determine if you have enough free space for recording.

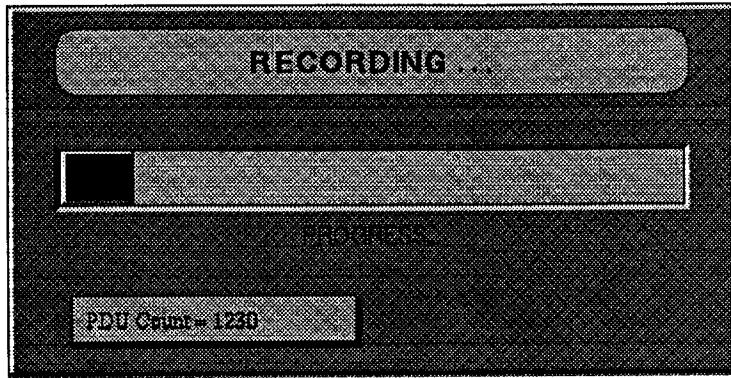


Figure A.3. Record Progress Form

Table A.5. Recording Time Versus Disk Space Requirements

ENTITY COUNT	TIME	SPACE	PDU COUNT
100	110 min.	250 MBs	1.5 Million
500	10 min.	21.5 MBs	70,000

When the simulation is over, press the STOP button to end the recording. The final PDU block is written to disk and your new recording is rewound for immediate replay. From here you can exit the VCR or replay the data as described in the next section.

A.4. *Replaying a Recording*

Unless you just finished recording the simulation exercise you want to replay, it will be necessary to select one. The next sections tell how selection is accomplished and walks you through the replay process, including the effects of speed controls.

A.4.1. *Select Exercise Form.* Before covering the selection procedure, it would be good to know what actions put you into the Select Exercise Form. There are two ways to invoke the select process. First, if you press PLAY and a file was not just recorded or selected, then the Select Exercise Form will automatically be displayed for you. Once a file has been loaded, the PLAY

button only affects that file. The second way to start a selection is to click on the SELECT EXERCISE button on the main VCR form.

Selection is accomplished by the form shown in Figure A.4. This form consists of a pick list, a file information box, various buttons, and two input fields used to set the data directory and file name filter or pattern. Each of these objects is covered in the following sections.

A.4.1.1. The Pick List. This list contains both directory and file names. If you click on a directory name (these have a "D" preceding them), the VCR switches to it and updates the pick list to reflect the change. If the items in the list do not fit in the window, a scrollbar is added to the side of the list to give you access to more entries. The scrollbar has a button you can drag to scroll the list or you can click on the bar above or below that button to page-up or page-down through the list.

When you select a file name, the file's information is displayed in the box on the right. This will help you identify which recording it is, when it was recorded, and what PDUs were originally captured.

A.4.1.2. The Buttons and Inputs. As you can see, there are four buttons included on this form. The CANCEL button allows you to exit the form and return to the previous state. Pressing LOAD means you are satisfied with your selection and want to play that file. If you entered this form from the press of the PLAY button, replay will begin immediately by displaying PRE-PROCESSING in a message. Otherwise, you are returned to the main VCR form and will have to select PLAY to begin. After the pre-processing message, a progress form, like that in record mode, pops-up and PDUs begin replaying. Just like record, updates to the progress form do not occur on every PDU. The frequency of updates will depend on the replay speed and the number of entities in a particular recording. Speed is discussed in detail in section A.4.2.

Figure A.4. Data Selection Form

The DELETE button allows you to purge old data from the disk. Periodically review all data files and backup or delete the ones you will no longer use, since VCR data files are typically large.

A press of the HELP button launches the form shown in Figure A.5, with specific help on the current form. This help system was borrowed from the Remote Debriefing Tool (RDT) and functions the same way. As with the pick list, if the information does not fit in the window, a scrollbar will give you access to the rest of the text. Buttons on the bottom act as an index to other help topics, press these buttons to load other topics. To exit help, choose the QUIT button.

Aside from clicking a directory name to change data directories, you can also type it in directly. Just click on the directory input field and enter the new one in the box that comes up. Limited error checking is done here, so try to be accurate. The file name pattern is changed the same way.

A.4.2. Replay Speed. When you selected a file, the VCR looked at the speed setting and started the replay at that speed. However, you can also change speeds during the replay as often as you choose. The receiving application's response to speed changes depends on whether or not it accepts and reacts to replay PDUs. What you will see in applications for slow or fast speeds and speed changes, is summed up in Table A.6. Typically, you will only want to use standard or fast speeds for applications that do not pay attention to replay PDUs.

Table A.6. Application Responses to Speed and Speed Changes

SPEED OR CHANGE	APP. USES REPLAY PDU	NON-REPLAY APP.
Fast	Dead-reckons smoothly through PDU updates.	Entities take forward leaps.
Slow	Same	Entities drop off and reload. Dead-reckoning leads the entity.
Slow to Fast	Net delay on Replay PDU to App. causes some initial forward leaping but smoothes out.	Switches from dropping entities to forward leaps.
Fast to Slow	Same Net delay causes some entities to initially drop, but OK after reloading.	Switch from forward leaping to dropping off or reverse leaps.

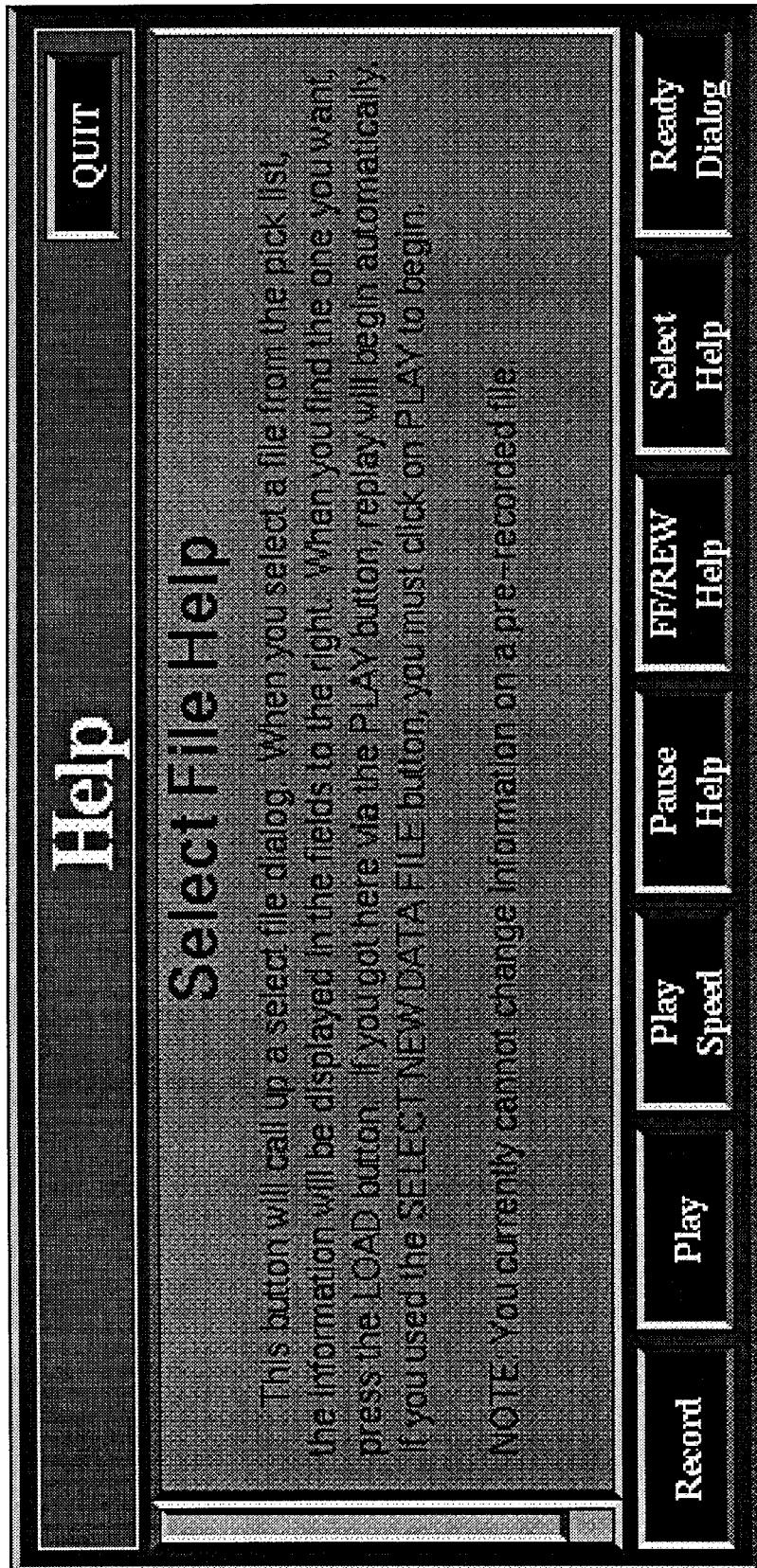


Figure A.5. Help Form

The radio buttons let you select from six fixed speed values ranging from 0.25 to 5.0. The selected button is lit up and its value displayed in the speed counter field. If the speed slider or counter buttons set the speed, the radio buttons are cleared and the new speed is displayed in the counter field.

A.4.3. Fast Forward and Rewind. Use the fast-forward (FF) or rewind (REW) buttons to move within the time range of the recording. To use these, a file must be loaded and stopped.

The FF button will advance the VCR's time until you press STOP or reach the stop time. If you did reach the end of the file, the VCR will place you at the start of the last PDU block and the time is set to the block's start time. The block will have at least one PDU and as many as 1000. When you stop in the middle of the recording, the VCR time will usually fall between the start and stop time of a block. When PLAY is selected again, PDUs are sent as fast as possible until PDU time catches the VCR clock, then play will continue at the selected speed.

The REW button is just the opposite of FF with one exception. When you rewind to the start or to a time within the first block, the file is pre-processed again before starting and the clock is set to the recording start time.

A.4.4. Pause. During a replay you may want to pause the VCR to examine a situation more closely. This is only possible for applications the respond to the replay PDU. When you select PAUSE, the VCR simply stops sending PDUs from the current block and transmits a replay PDU to inform the application. The application maintains the current simulation state and will not discard any entities from lack of PDUs. The pause form has a RESUME button that will restart the replay from where it paused.

A.5. Wrapping it up

Recording and replaying with the AFIT DIS VCR is nearly as simple as the home VCR. The real difference is the network setup and the selection of files instead of video tapes. Although the files use much disk space, they are valuable tools. The VCR gives you the capability to set up a complex demo, record it, then replay it over and over easily. It is used in engagement analysis with RDT or any simulation exercise.

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Vita

Captain Fortner was born on 28 December 1959 in Oakland, Indiana. He graduated from John Marshall High School in Indianapolis, Indiana in 1978 and enlisted in the U.S. Air Force on 12 January 1979. Following his selection for the Airman Education and Commissioning Program in 1987, he attended the University of Missouri - Rolla. Afterwards, he attended Air Force Officers Training School and was commissioned on 1 October 1990. Acceling in his first assignment at Headquarters Ballistic Missile Organization as an Interface Control Project Officer, he was awarded the Air Force Commendation Medal. In 1993 Captain Fortner was selected to attend the Air Force Institute of Technology to complete a Master of Science degree in Electrical Engineering. He is married to Christine Lynn (Beach) Fortner of Indianapolis, Indiana. They have three children: Jonathan, Geneva, and Jared.

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